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(54) SYSTEMS AND METHODS OF POWER GENERATION WITH AQUIFER STORAGE AND RECOVERY SYSTEM

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(21) Appl. No.: **17/124,243**

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Related U.S. Application Data

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(51) **Int. Cl.**
F03B 13/00 (2006.01)
F03B 13/06 (2006.01)

(52) **U.S. Cl.**
CPC ***F03B 13/06*** (2013.01)

(58) **Field of Classification Search**
CPC F05B 2210/11; F05B 2220/703; F05B 2220/7062; F05B 2260/422; F05B 2270/301; F05B 2270/327; F03G 7/04; F03B 13/06
See application file for complete search history.

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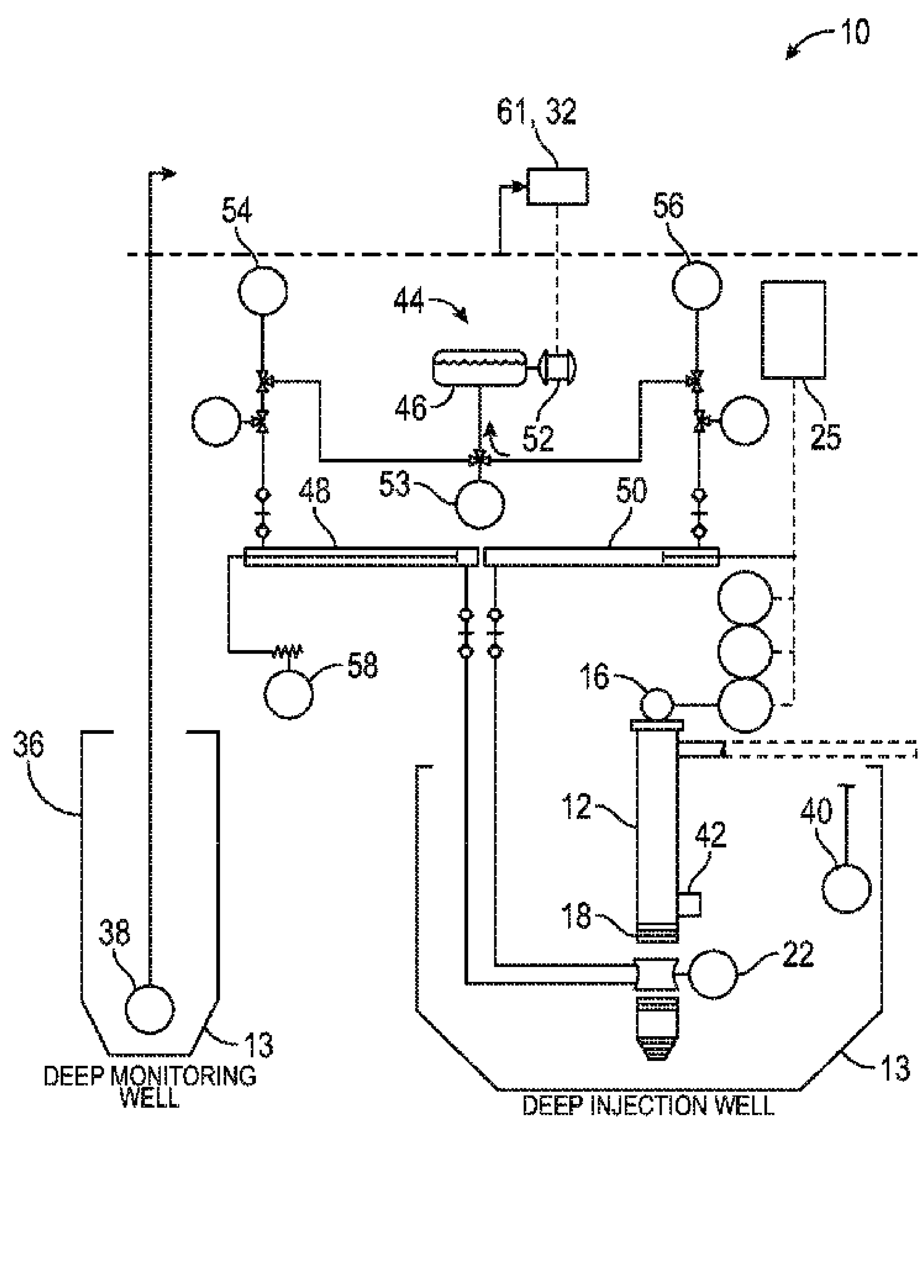
(74) *Attorney, Agent, or Firm* — Klarquist Sparkman, LLP

(57) **ABSTRACT**

An aquifer storage and recovery system can include a pump, an electric motor coupled to the pump, a drive unit configured to control operation of the electric motor, and a controller. The controller can be configured to flow water into a well bore from a source reservoir through the pump such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate as a generator, determine a power output of the electric motor, determine a difference between the power output of the electric motor and a power output set point, and operate the drive unit to control a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the power output set point.

22 Claims, 16 Drawing Sheets



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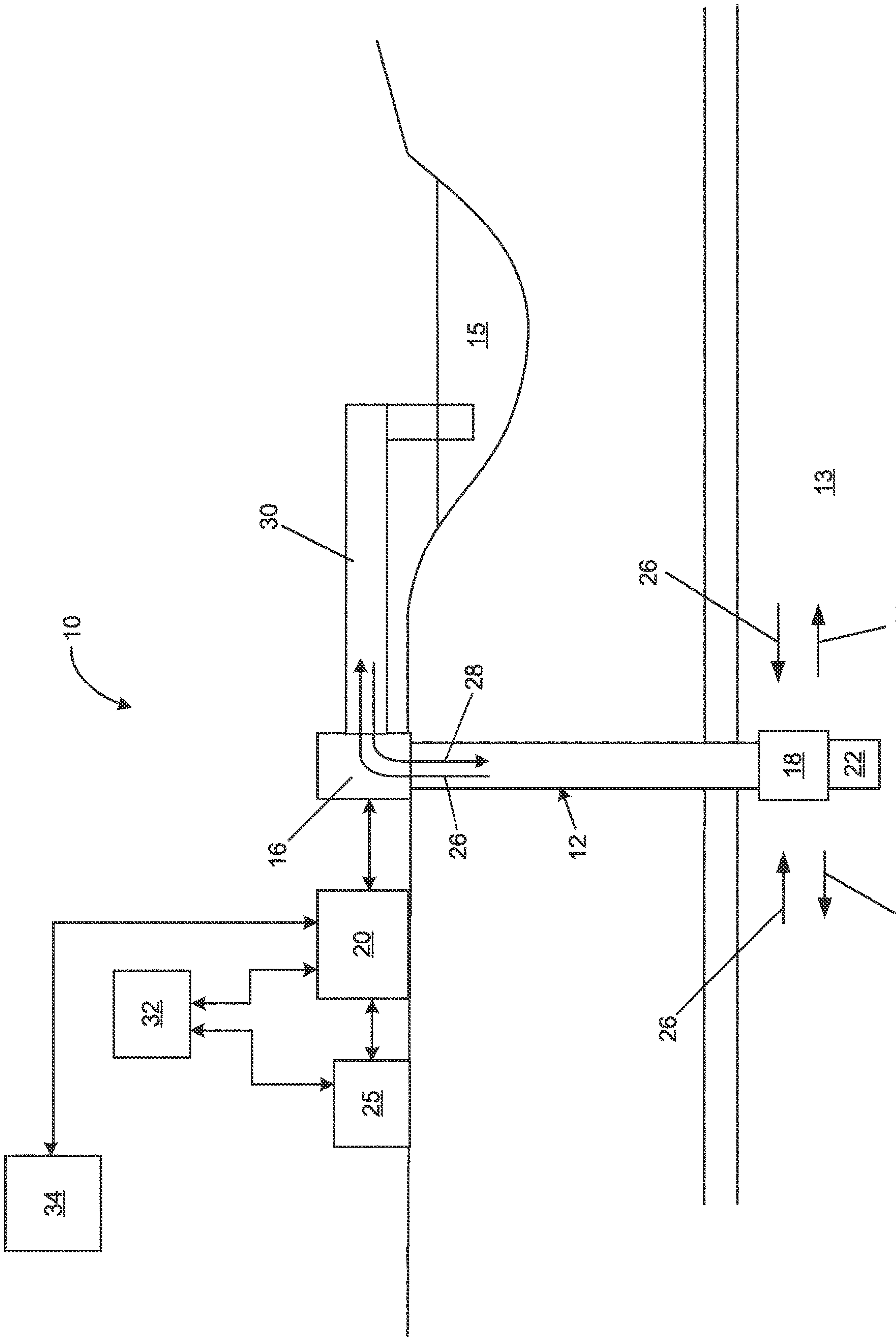


FIG. 1

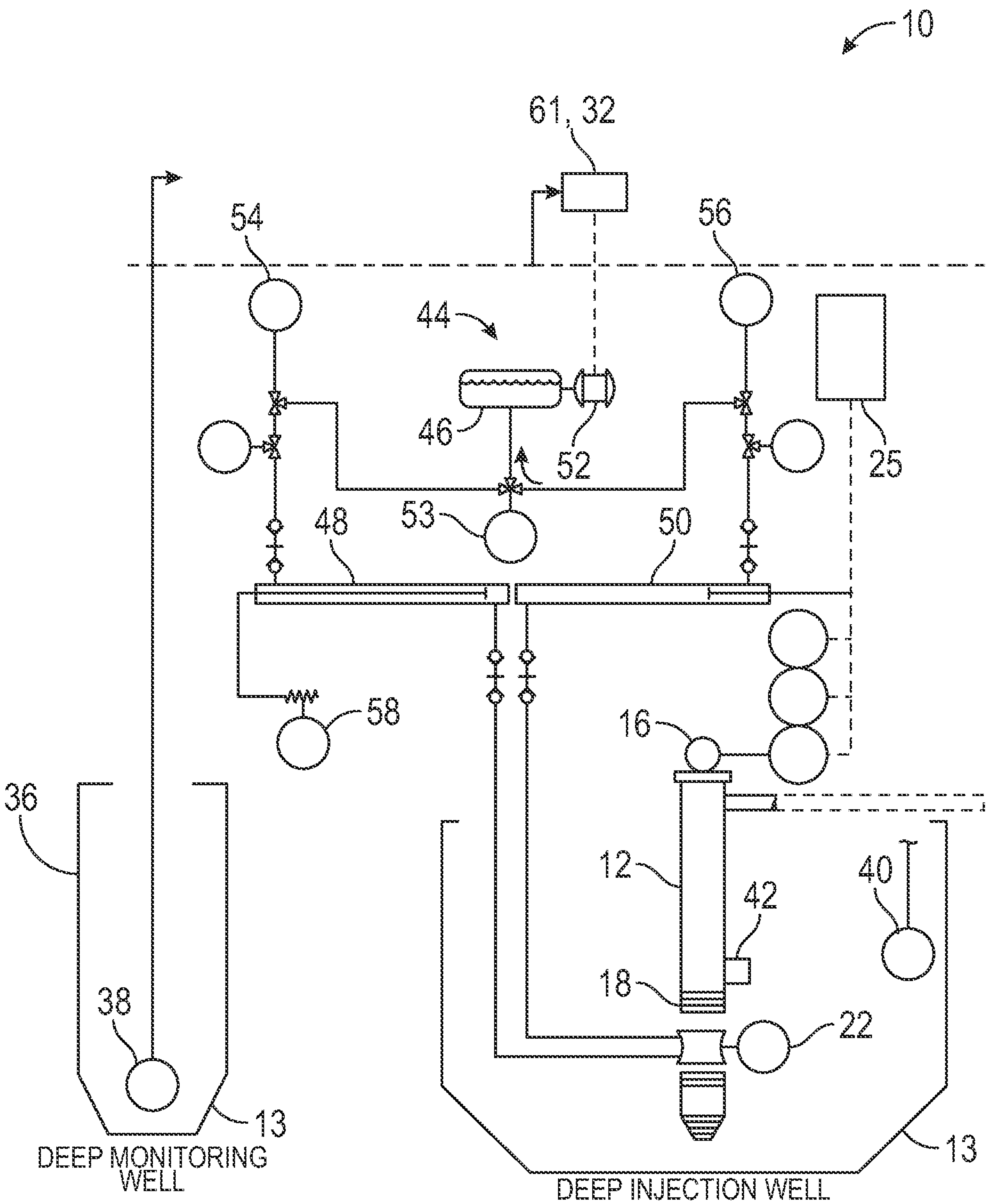

10
61, 32
54
56
44
46
52
25
53
48
50
58
16
36
12
42
40
18
38
22
13
DEEP MONITORING WELL
13
DEEP INJECTION WELL

FIG. 2

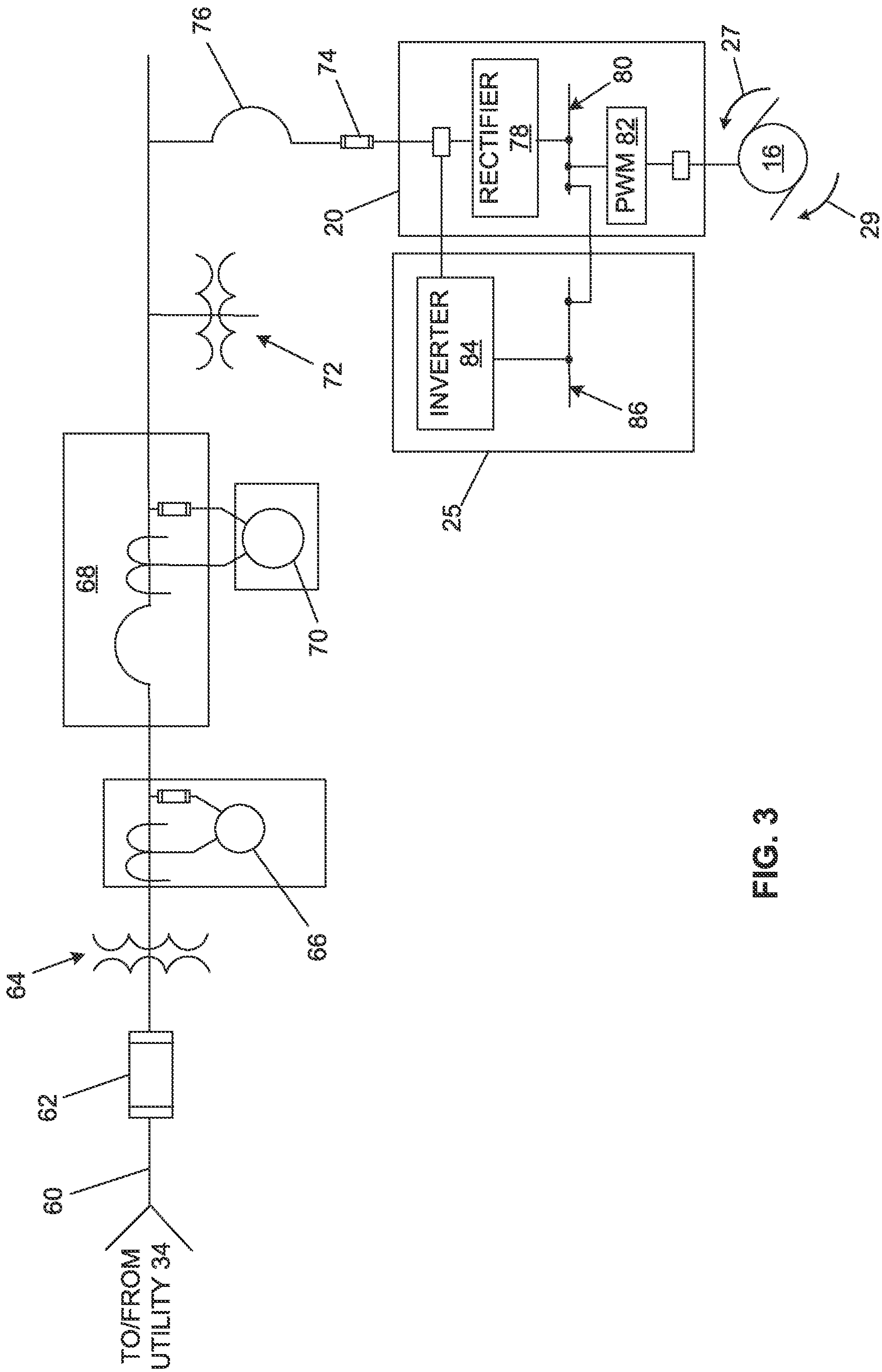

TO/FROM UTILITY 34
60
62
64
66
68
70
72
74
76
20
RECTIFIER 78
80
PWM 82
16
27
29
INVERTER 84
86
25

FIG. 3

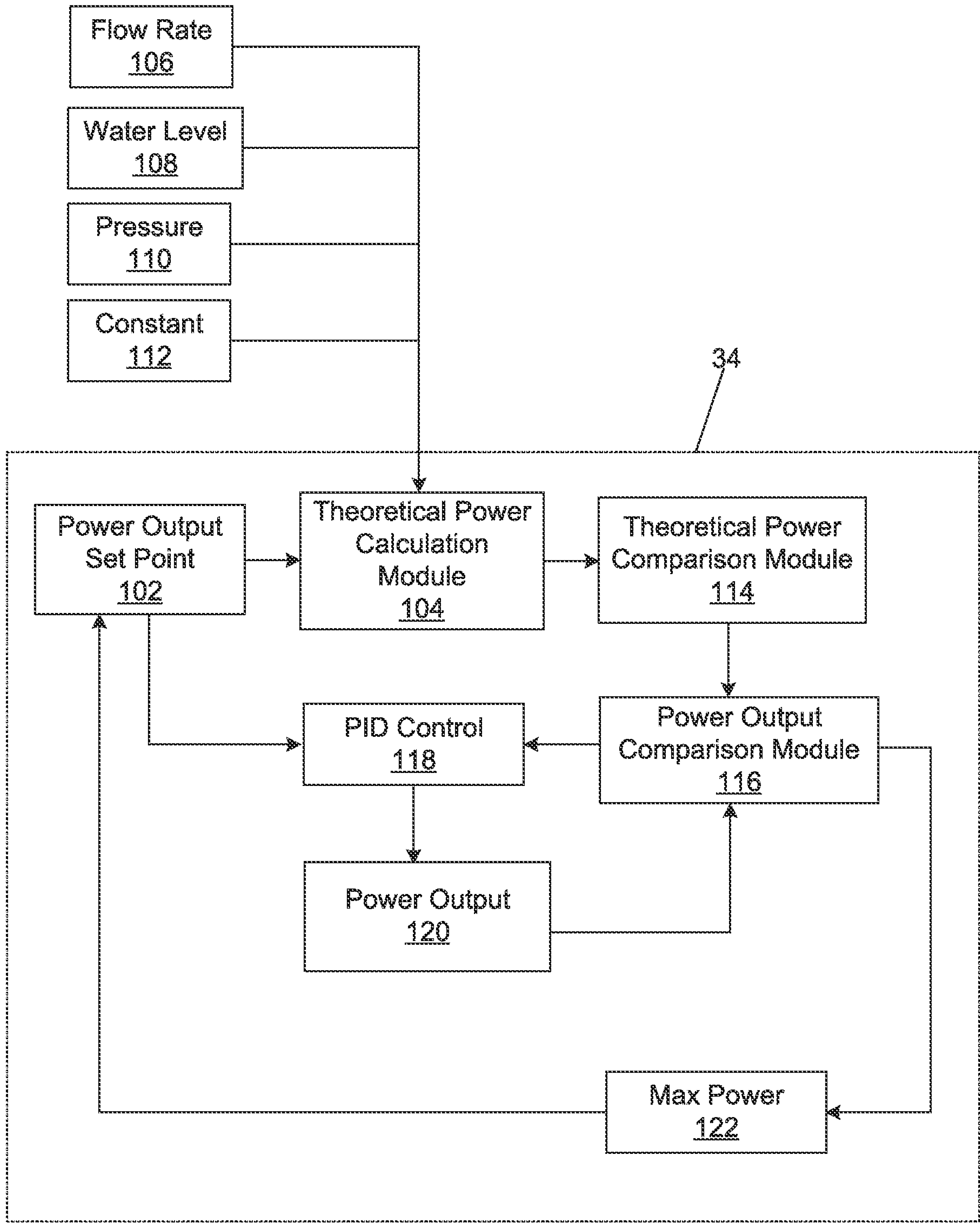

Flow Rate
106
Water Level
108
Pressure
110
Constant
112
34
Power Output
Set Point
102
Theoretical Power
Calculation
Module
104
Theoretical Power
Comparison Module
114
PID Control
118
Power Output
Comparison Module
116
Power Output
120
Max Power
122

FIG. 4

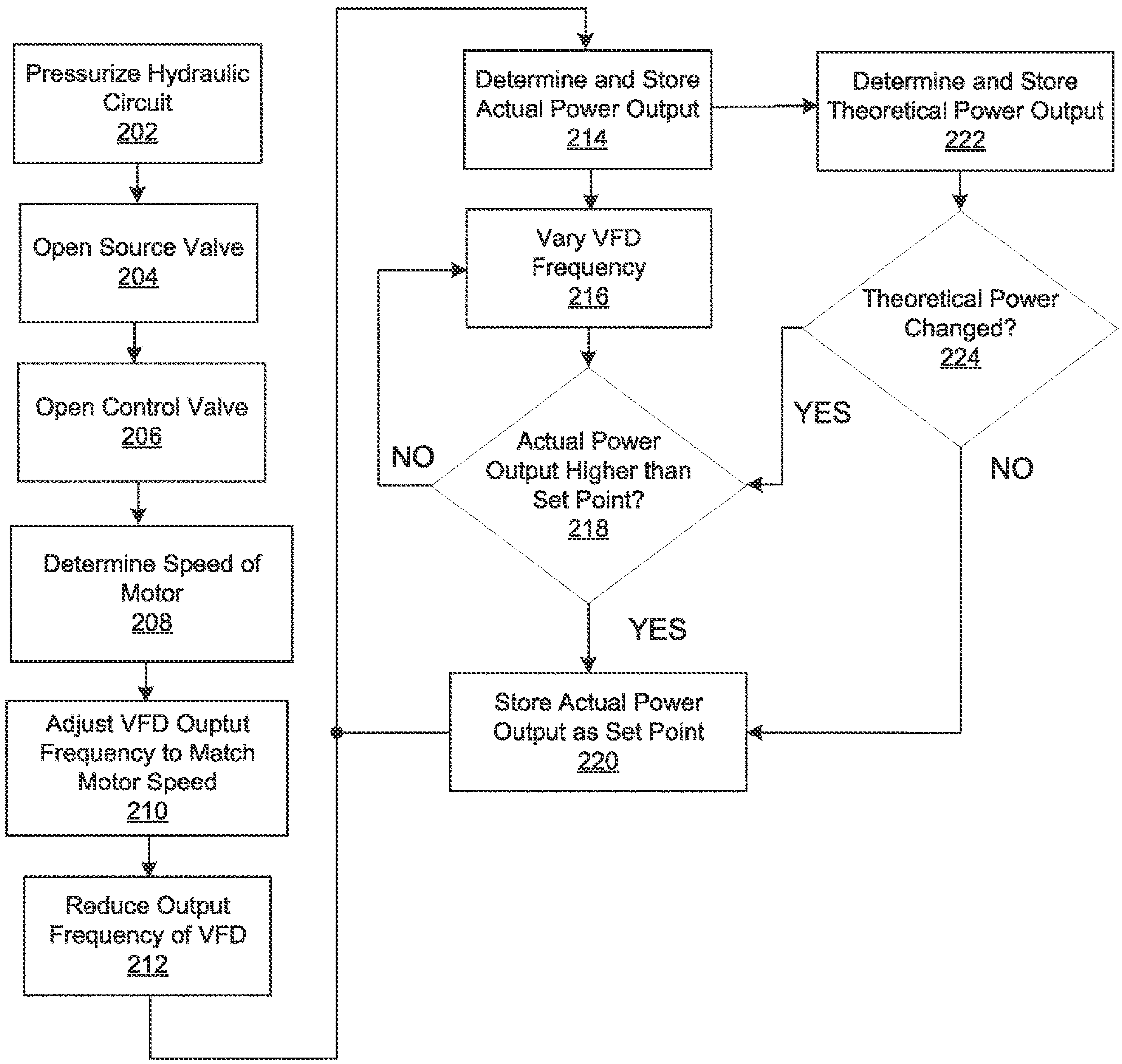
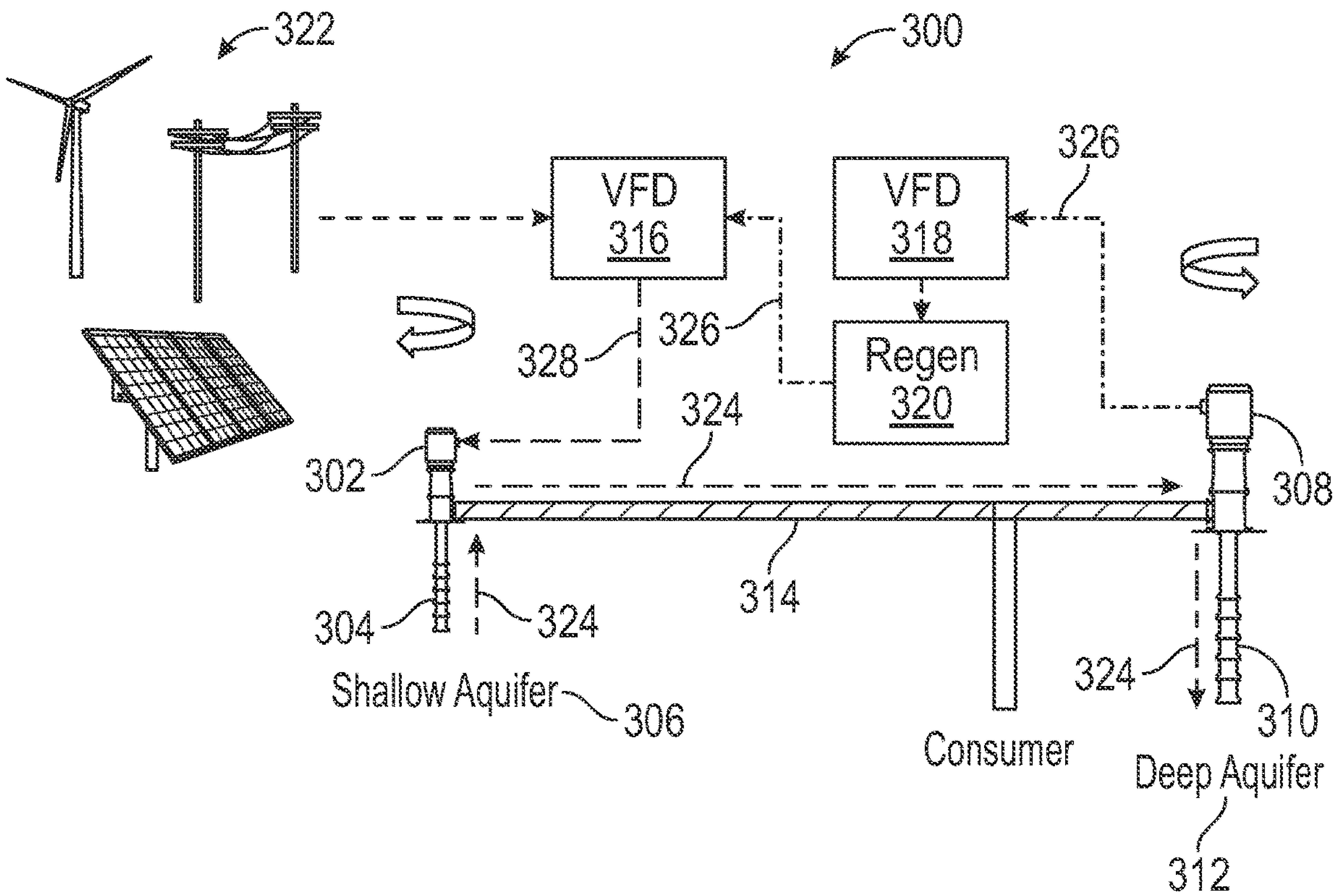
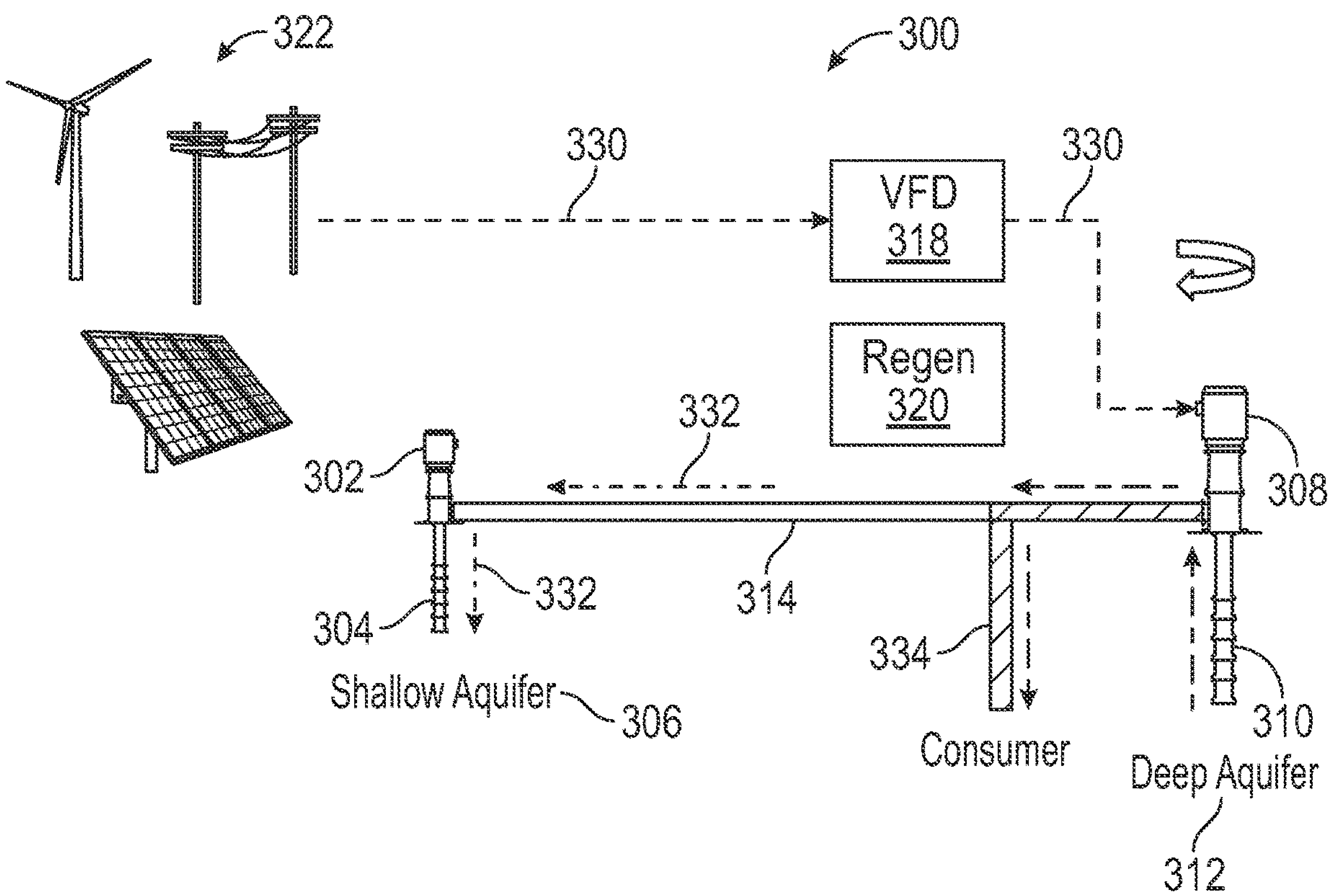

Pressurize Hydraulic Circuit
202
Open Source Valve
204
Open Control Valve
206
Determine Speed of Motor
208
Adjust VFD Ouptut Frequency to Match Motor Speed
210
Reduce Output Frequency of VFD
212
Determine and Store Actual Power Output
214
Vary VFD Frequency
216
Actual Power Output Higher than Set Point?
218
NO
YES
Store Actual Power Output as Set Point
220
Determine and Store Theoretical Power Output
222
Theoretical Power Changed?
224
YES
NO

FIG. 5



322
300
VFD
316
VFD
318
326
Regen
320
326
328
324
302
308
314
304
324
324
Shallow Aquifer
306
310
Consumer
Deep Aquifer
312

FIG. 6



322
300
330
330
VFD
318
Regen
320
332
302
308
314
332
304
334
Shallow Aquifer
306
310
Consumer
Deep Aquifer
312

FIG. 7

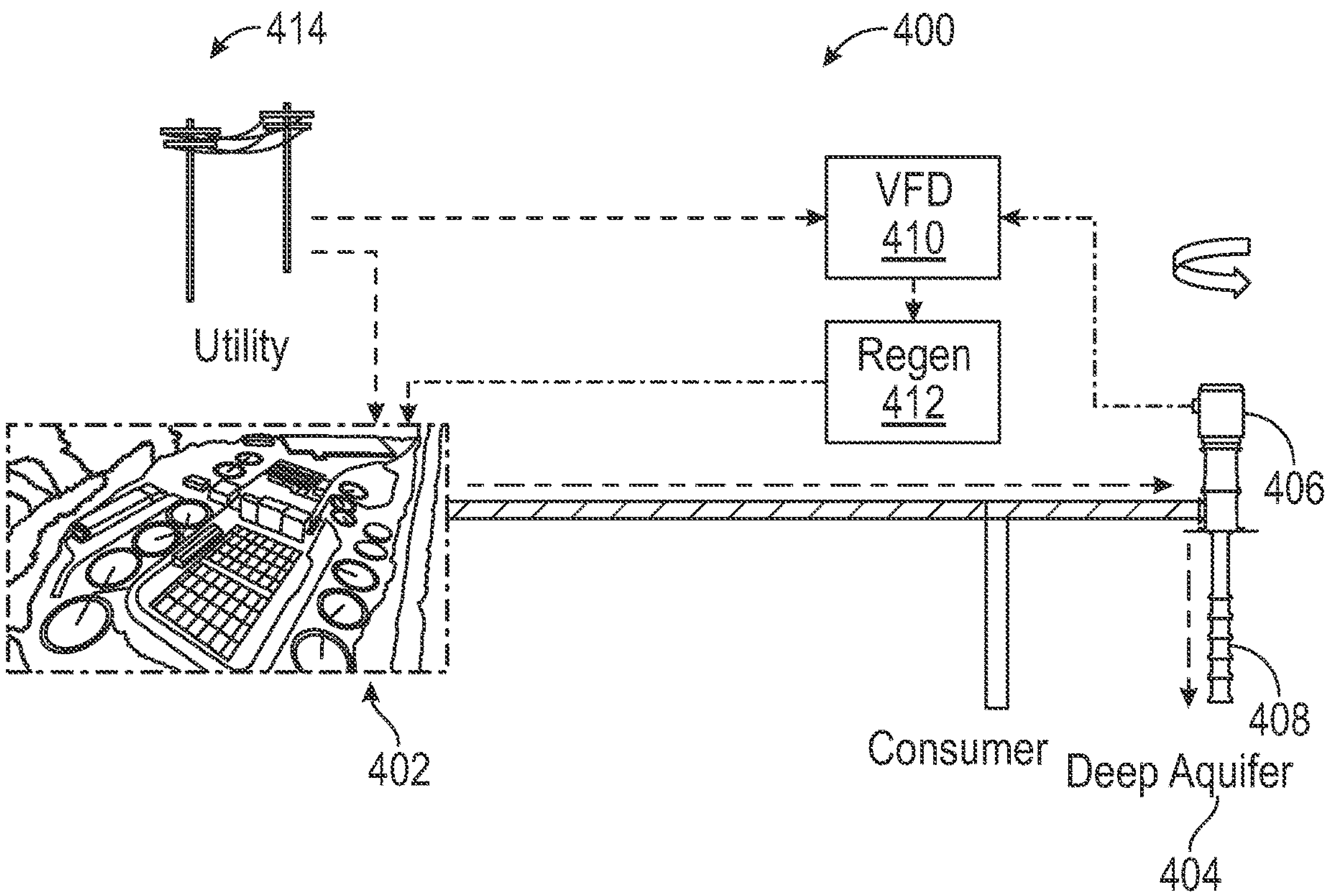

414
400
VFD
410
Regen
412
Utility
406
408
Consumer
Deep Aquifer
402
404

FIG. 8

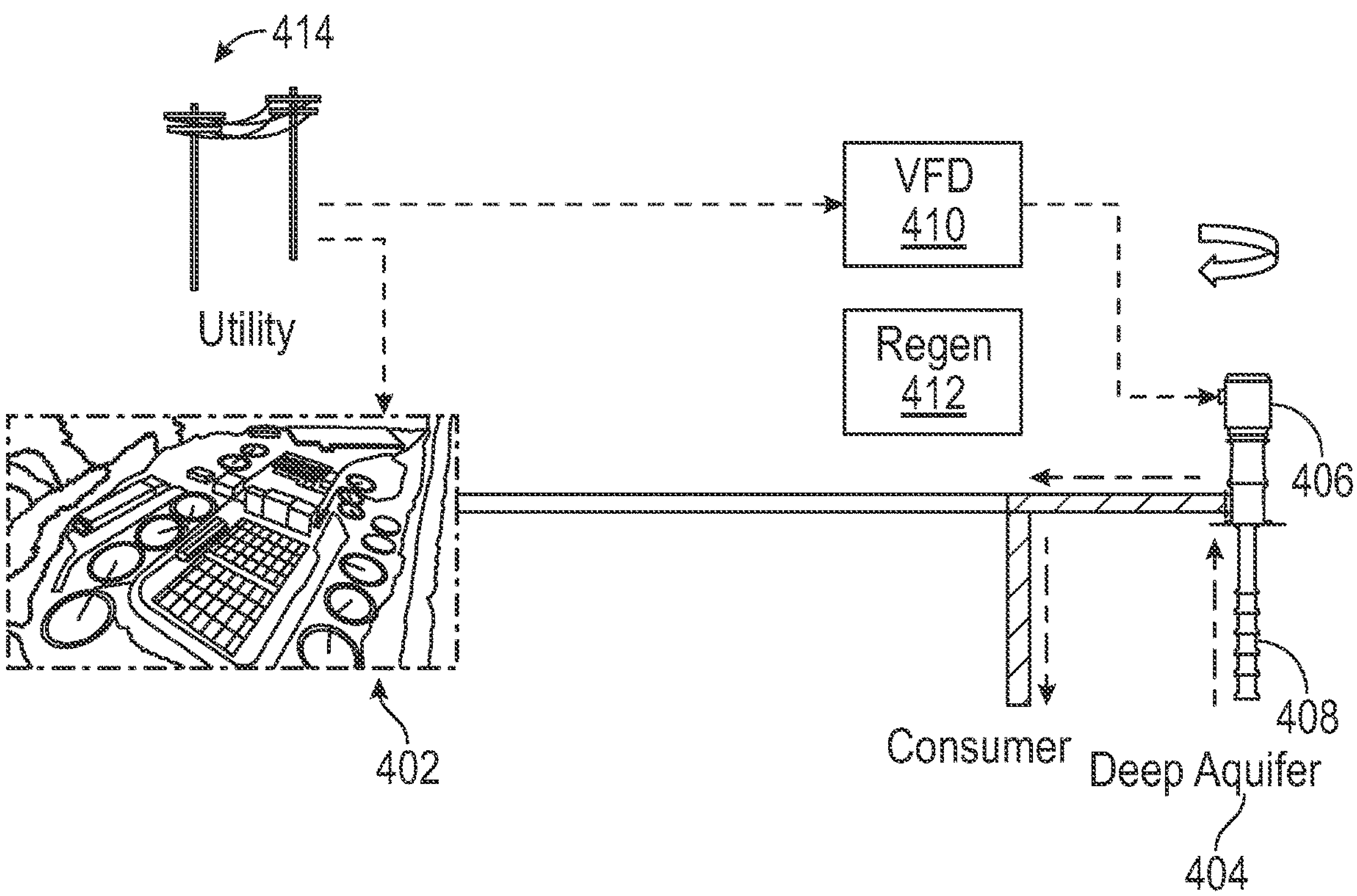

414
VFD
410
Regen
412
Utility
406
408
Consumer
Deep Aquifer
402
404

FIG. 9

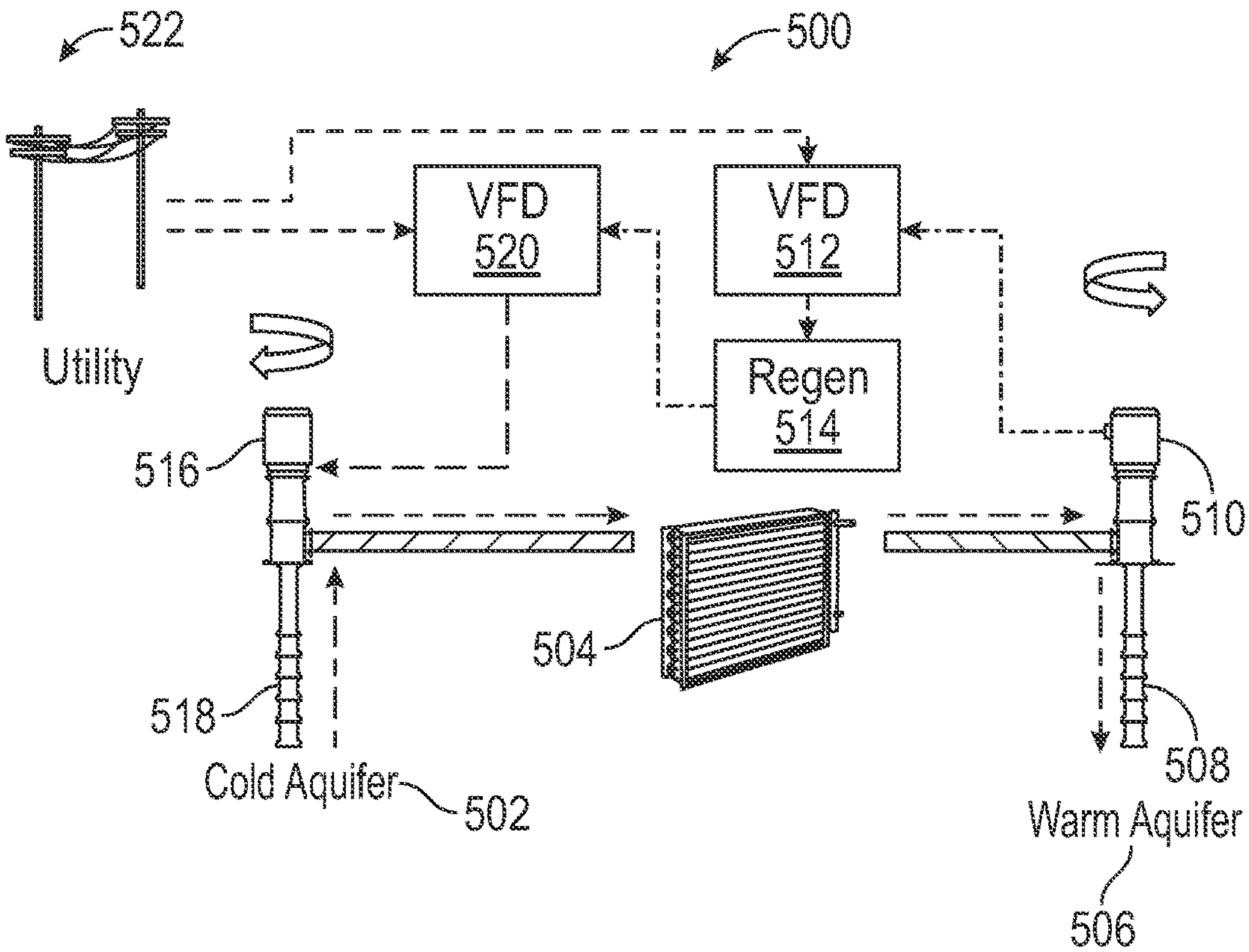

522
500
VFD
520
VFD
512
Utility
Regen
514
516
510
504
518
508
Cold Aquifer
502
Warm Aquifer
506

FIG. 10

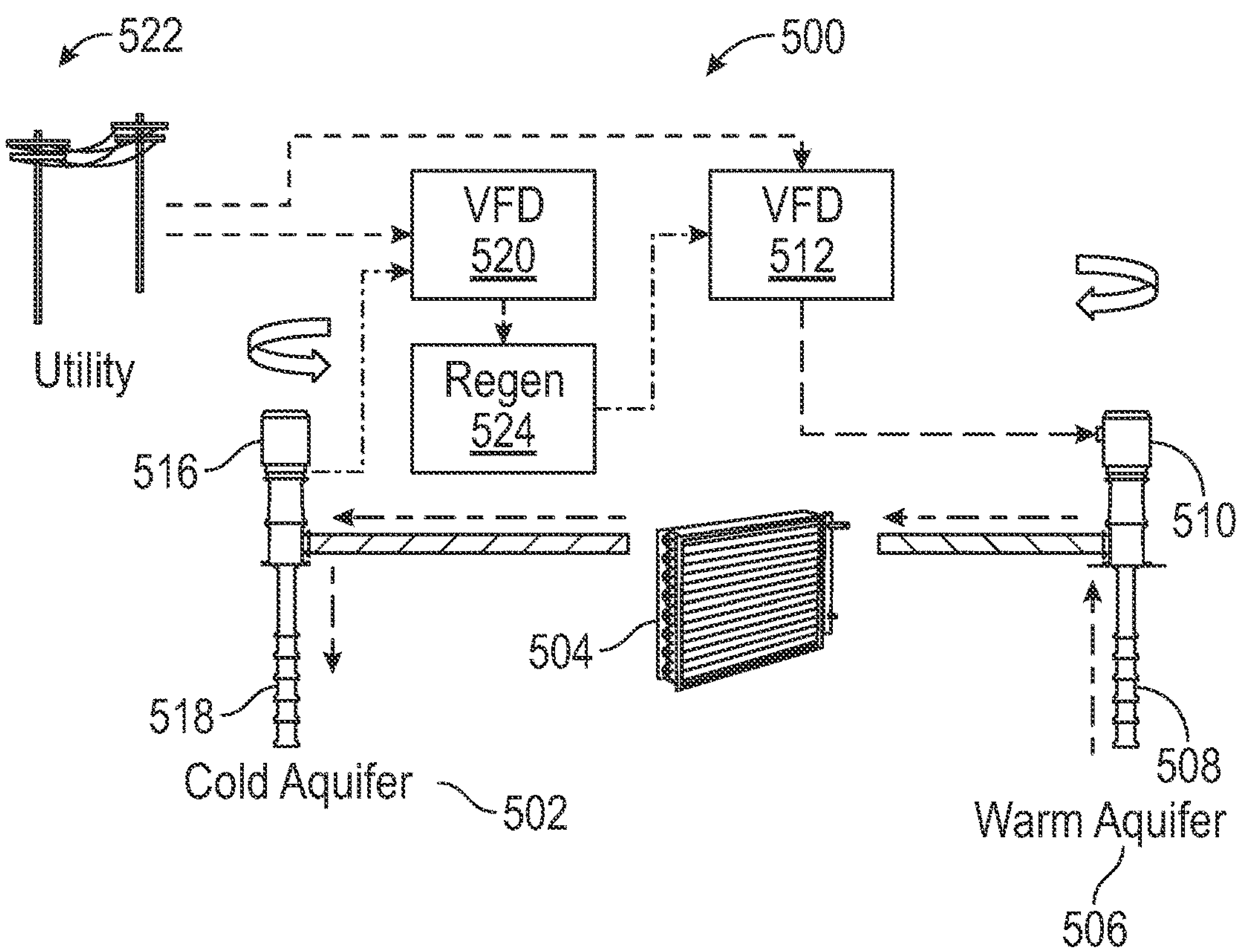

522
500
VFD
520
VFD
512
Utility
Regen
524
516
510
504
518
508
Cold Aquifer
502
Warm Aquifer
506

FIG. 11

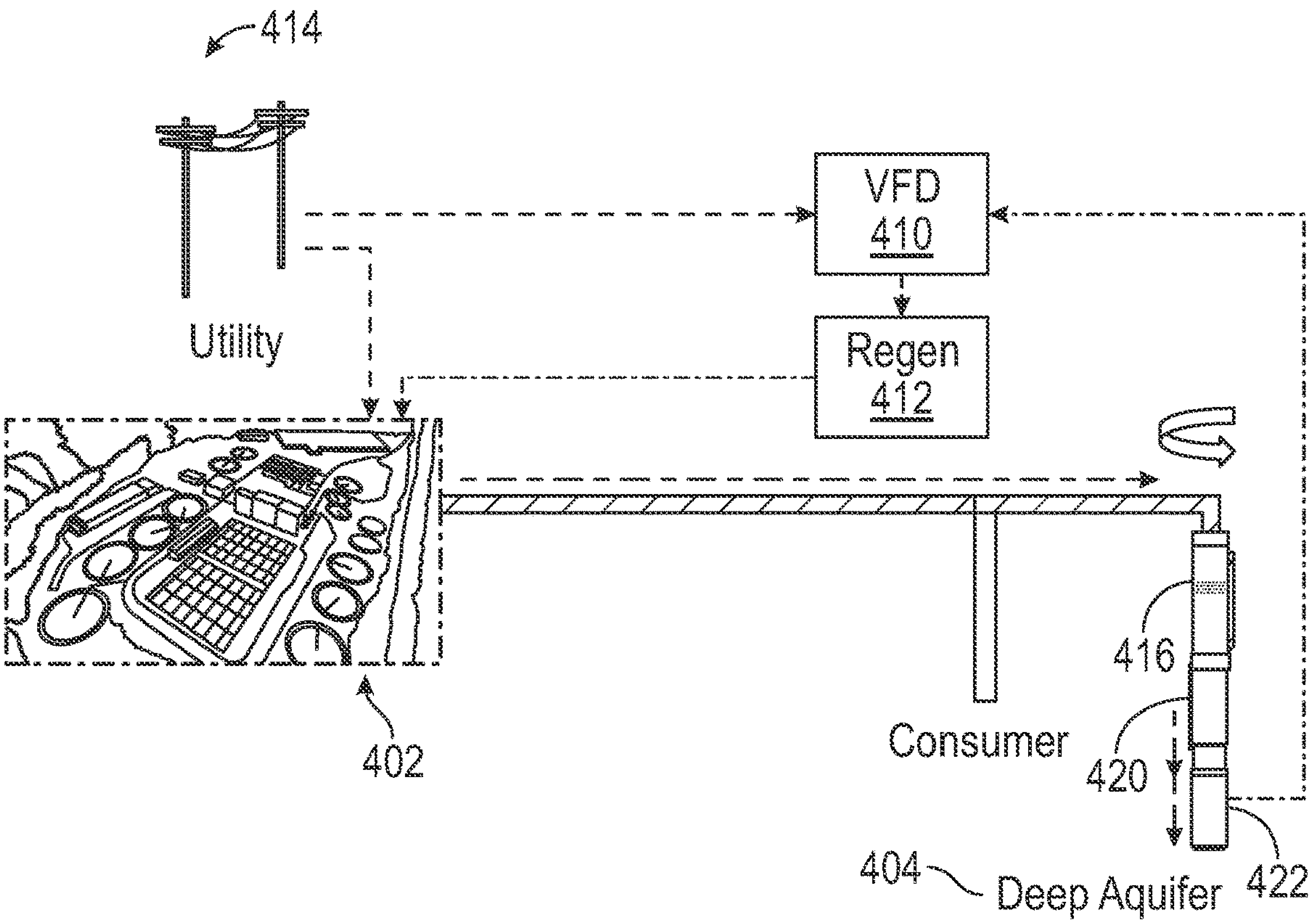

414
Utility
VFD
410
Regen
412
402
Consumer
416
420
422
404
Deep Aquifer

FIG. 12

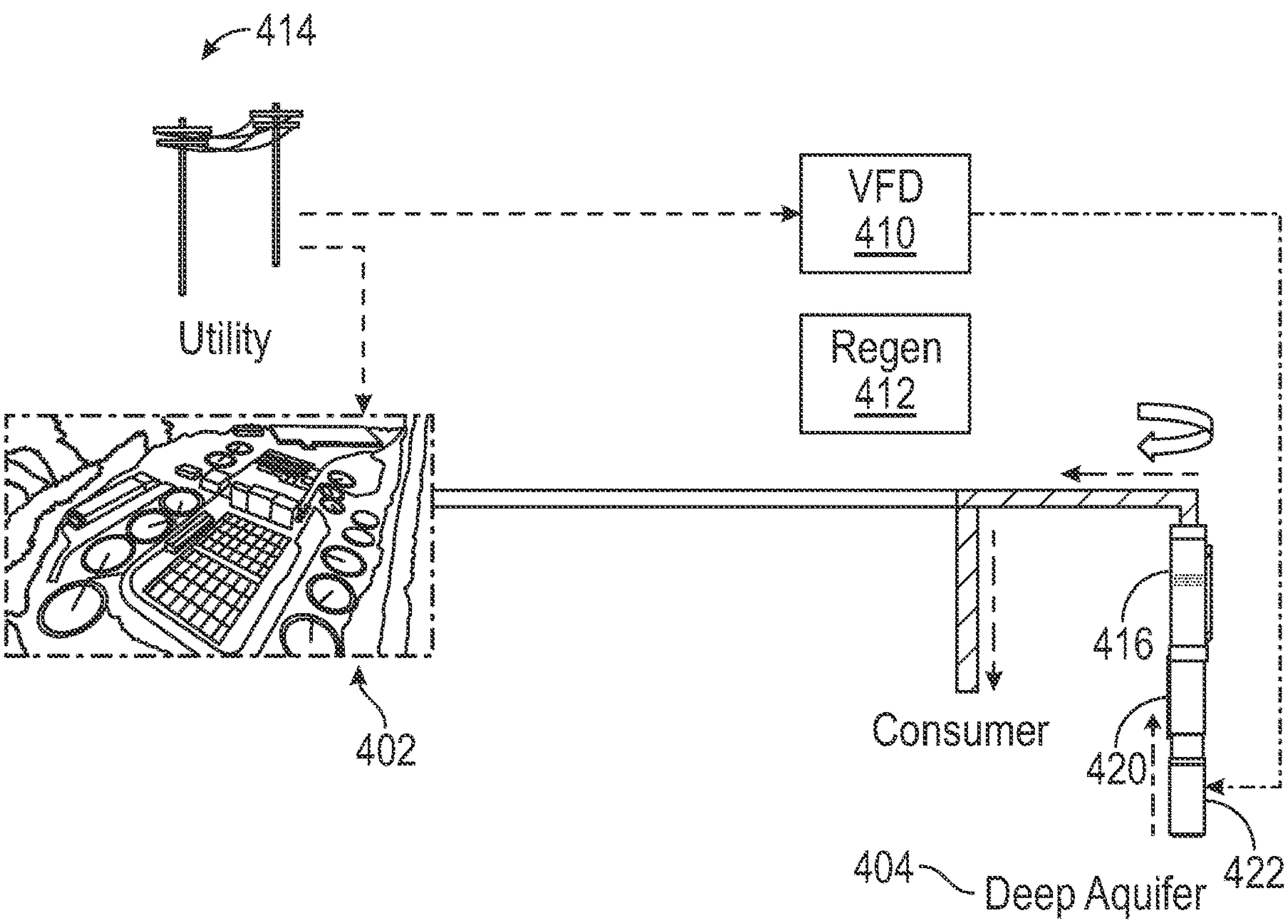

414
Utility
VFD
410
Regen
412
402
Consumer
416
420
422
404
Deep Aquifer

FIG. 13

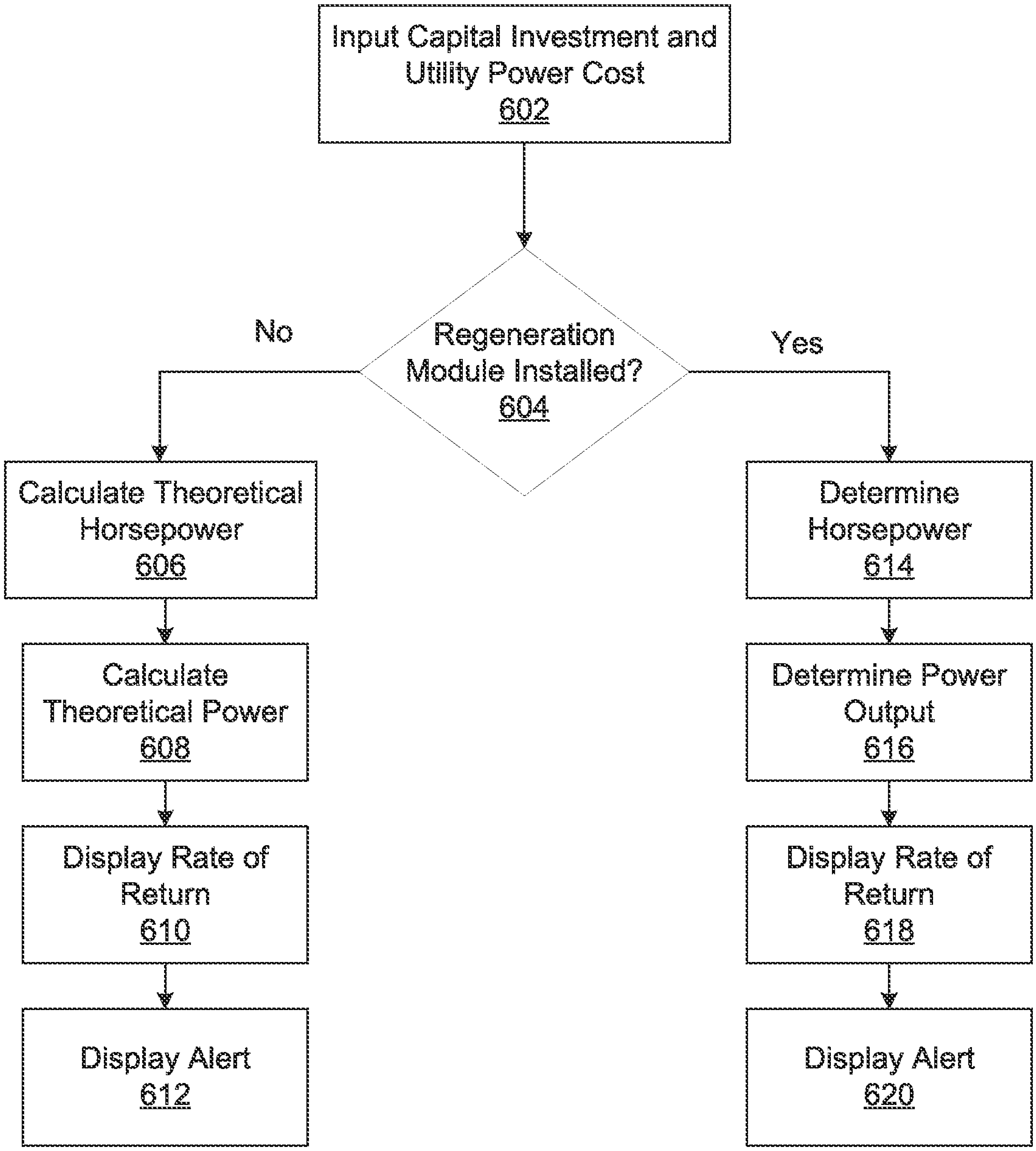

Input Capital Investment and Utility Power Cost
602
Regeneration Module Installed?
604
No
Yes
Calculate Theoretical Horsepower
606
Calculate Theoretical Power
608
Display Rate of Return
610
Display Alert
612
Determine Horsepower
614
Determine Power Output
616
Display Rate of Return
618
Display Alert
620

FIG. 14

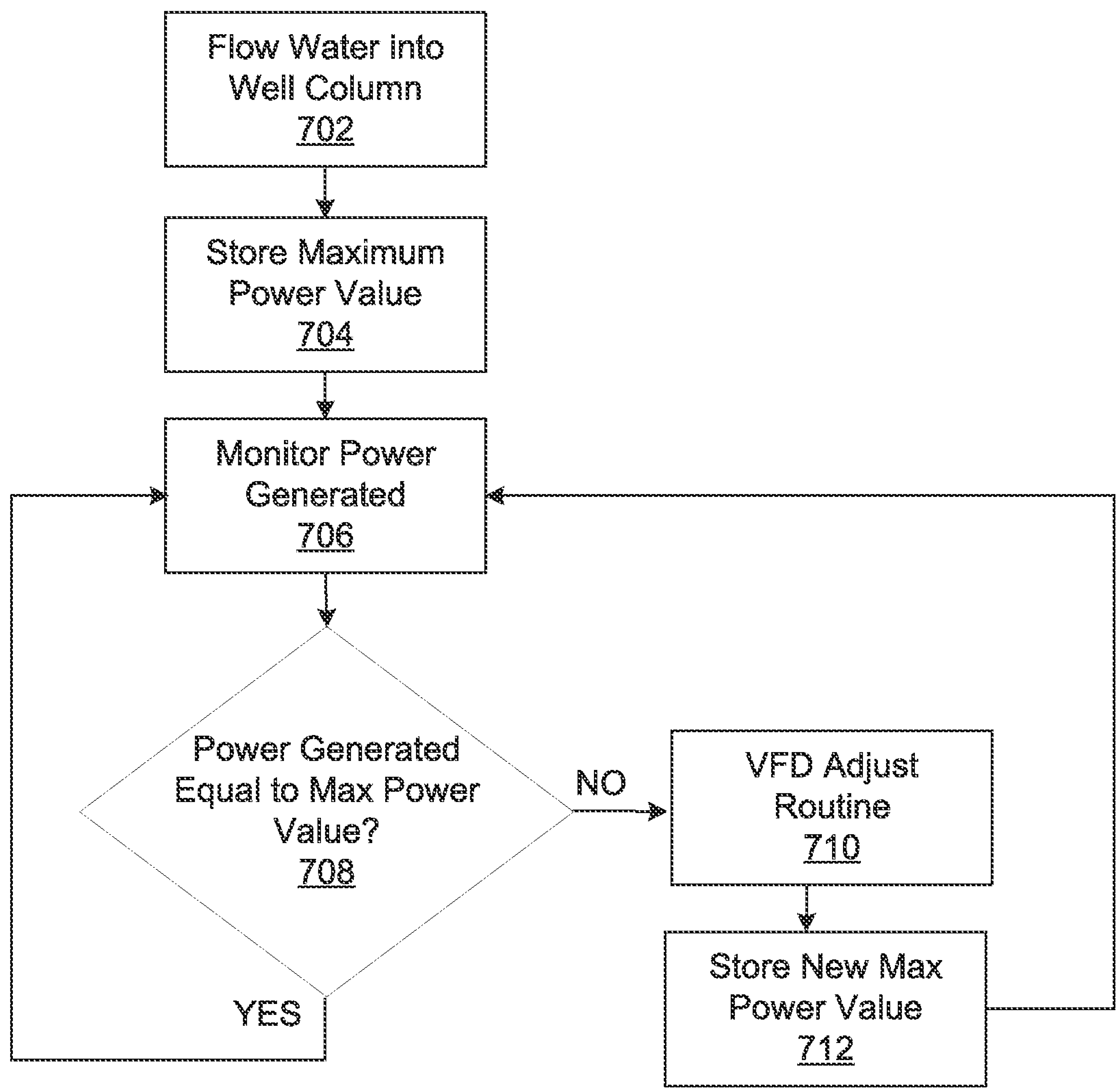

Flow Water into Well Column
702
Store Maximum Power Value
704
Monitor Power Generated
706
Power Generated Equal to Max Power Value?
708
NO
YES
VFD Adjust Routine
710
Store New Max Power Value
712

FIG. 15

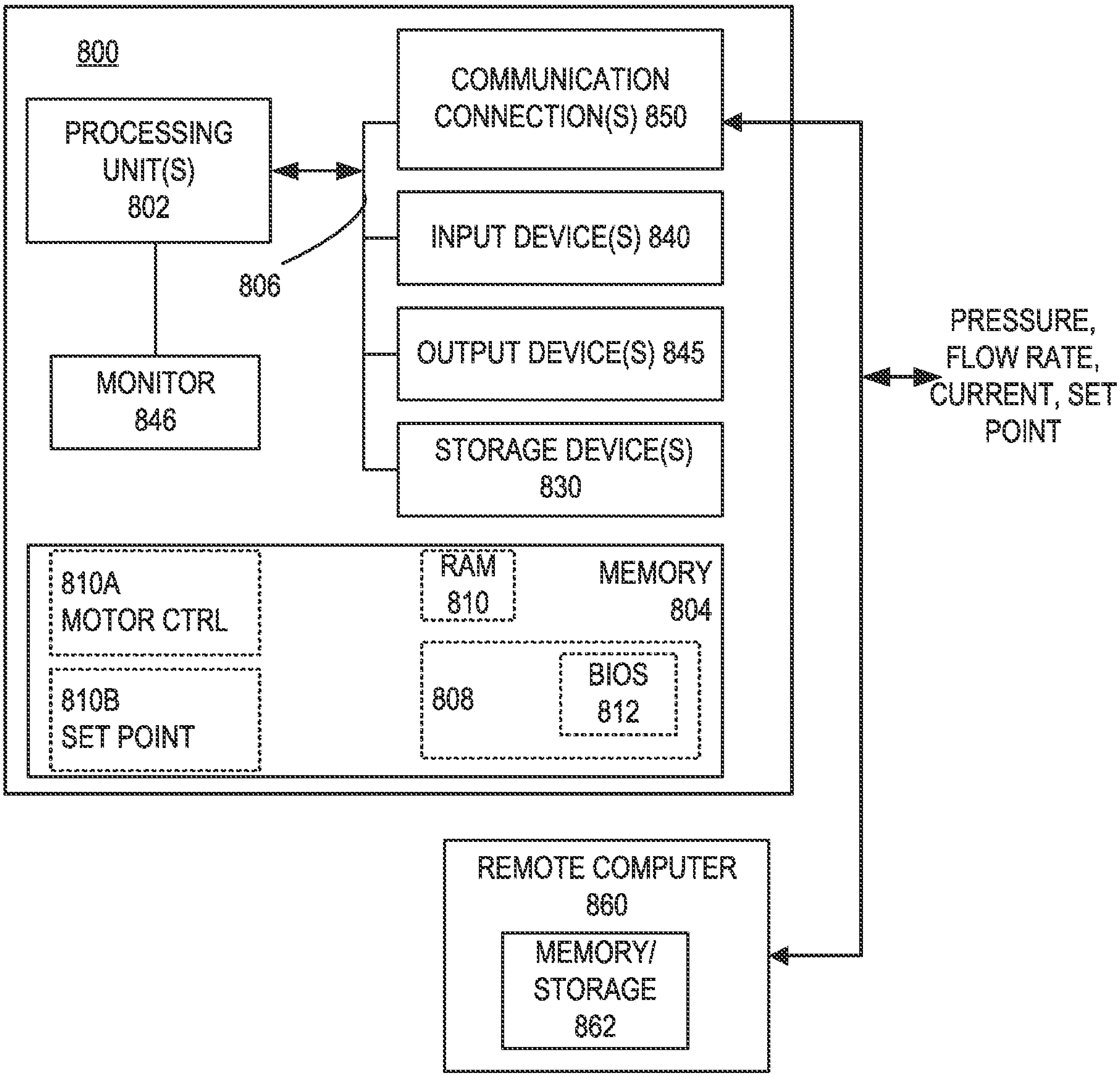

800
PROCESSING UNIT(S) 802
COMMUNICATION CONNECTION(S) 850
INPUT DEVICE(S) 840
806
OUTPUT DEVICE(S) 845
MONITOR 846
STORAGE DEVICE(S) 830
PRESSURE, FLOW RATE, CURRENT, SET POINT
810A MOTOR CTRL
RAM 810
MEMORY 804
810B SET POINT
808
BIOS 812
REMOTE COMPUTER 860
MEMORY/ STORAGE 862

FIG. 16

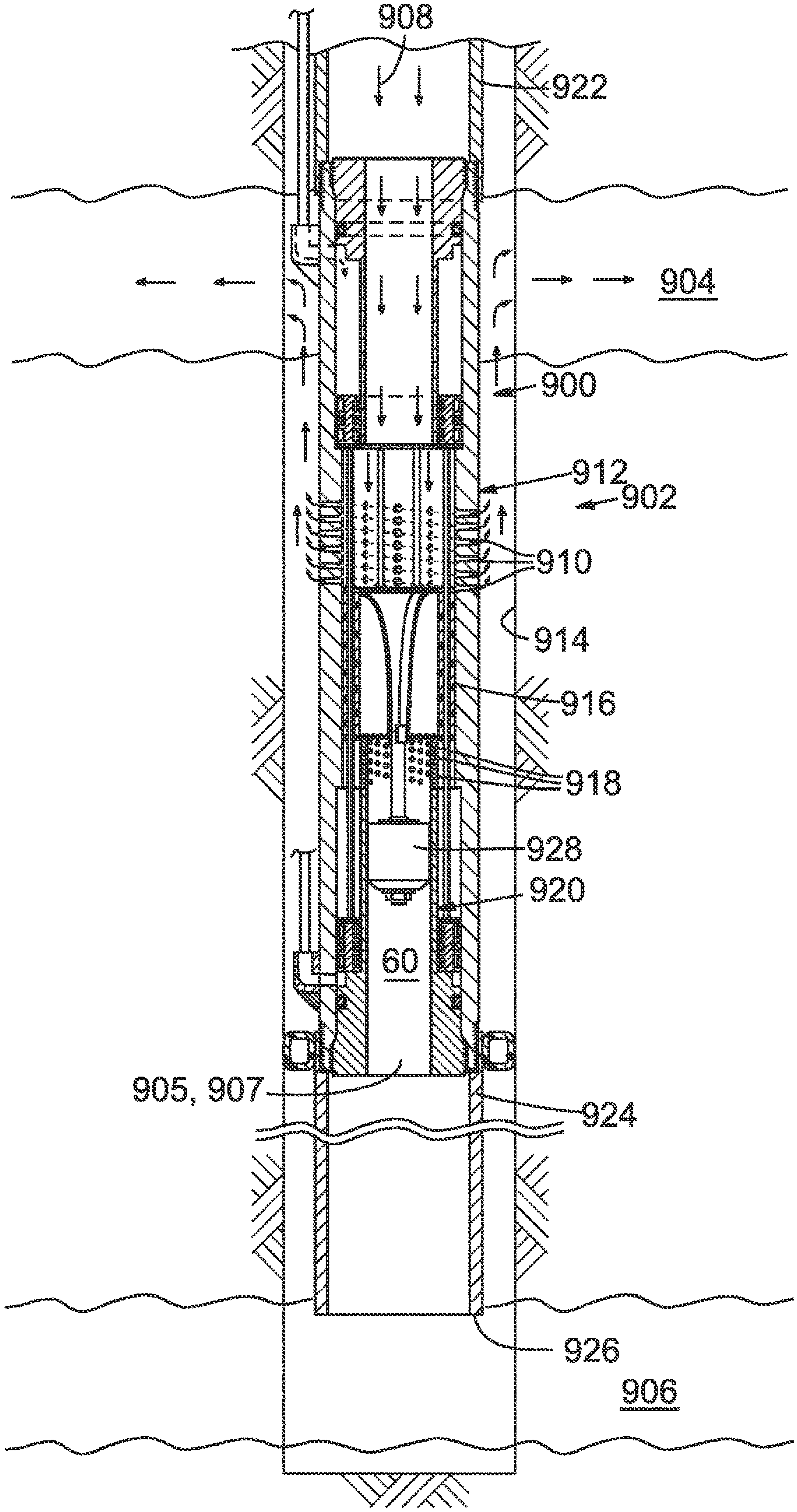

908
922
904
900
912
902
910
914
916
918
928
920
60
905, 907
924
926
906

FIG.17

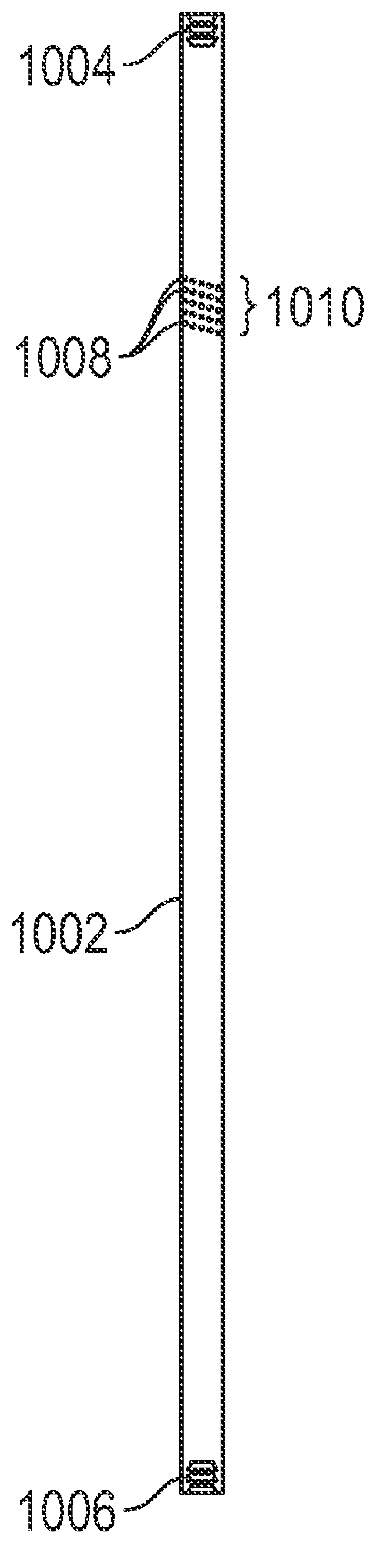
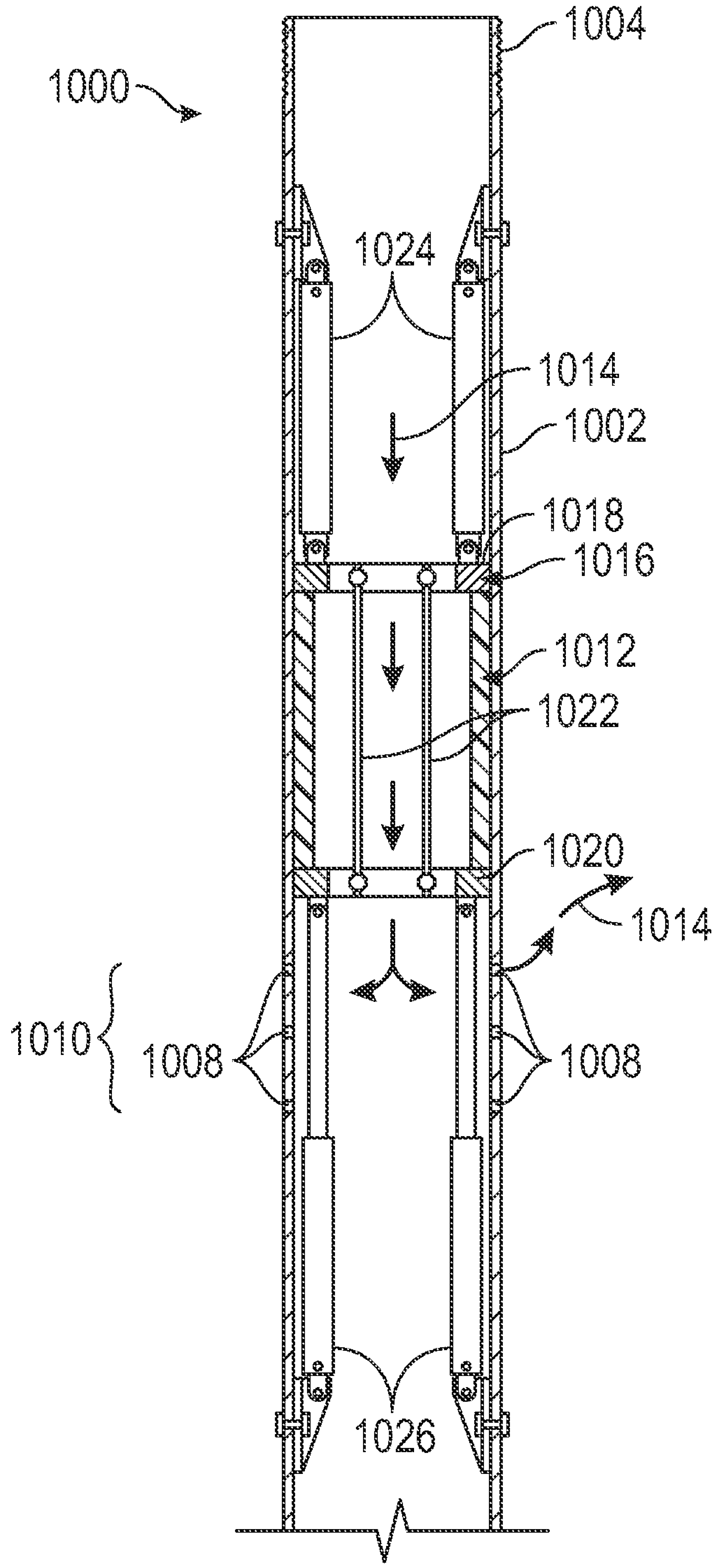

1004
1010
1008
1002
1006

FIG. 18


1004
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1024
1014
1002
1018
1016
1012
1022
1020
1014
1010
1008
1008
1026

FIG. 19

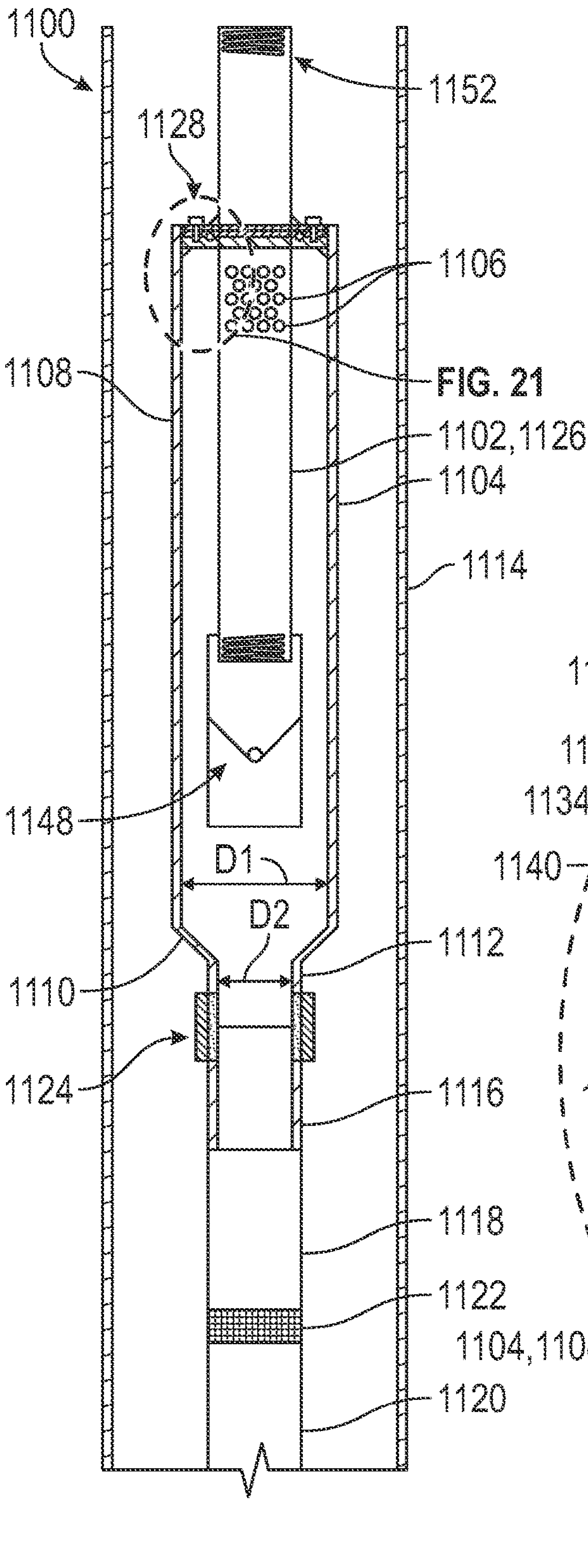
1100
1152
1128
1106
FIG. 21
1108
1102,1126
1104
1114
1148
D1
D2
1112
1110
1124
1116
1118
1122
1120

FIG. 20

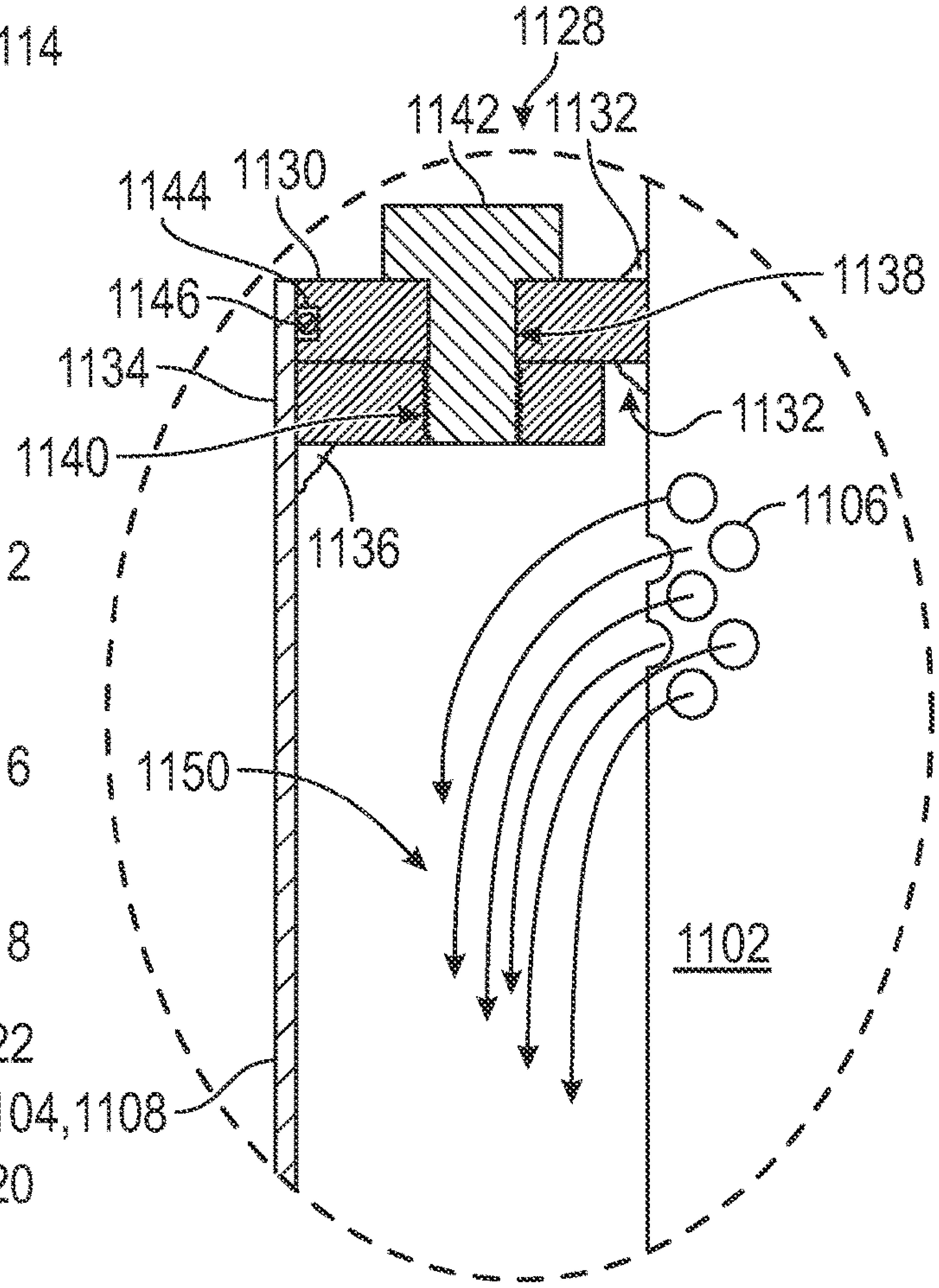
1128
1142
1132
1144
1130
1138
1146
1134
1132
1140
1136
1106
1150
1102
1104,1108

FIG. 21

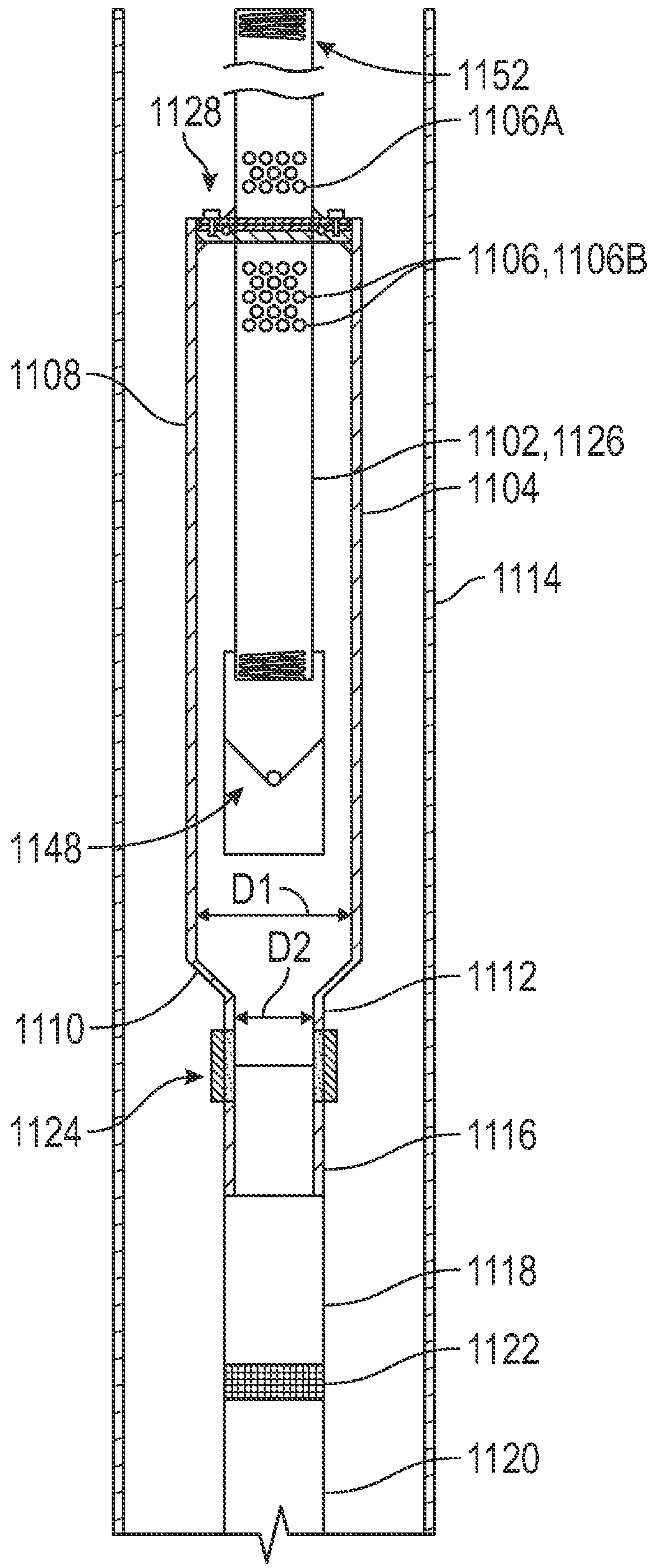
1152
1128
1106A
1106,1106B
1108
1102,1126
1104
1114
1148
D1
D2
1112
1110
1124
1116
1118
1122
1120

FIG. 22

SYSTEMS AND METHODS OF POWER GENERATION WITH AQUIFER STORAGE AND RECOVERY SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit of U.S. Provisional Application No. 62/971,874, filed Feb. 7, 2020, which is incorporated by reference herein in its entirety.

FIELD

The present disclosure pertains to systems and methods of generating electricity when water is supplied from a source reservoir to an aquifer through a well.

BACKGROUND

In many geographic areas, aquifers are a primary source of water for use in agriculture and for other purposes. Water can be withdrawn from the aquifer through a well bore using a pump system typically including a pump, a motor, valves, and a control system. Water can be returned to the aquifer through the well bore to charge or replenish the aquifer during, for example, periods of excess rainfall, so that the water stored in the aquifer is then available during dry times of year. When water is returned to the aquifer through the well bore, the pressure head developed in the well bore column can be significant, depending on the depth of the well bore. However, existing pump systems are not configured to efficiently generate electricity during the aquifer recharge process, if at all. Accordingly, there exists a need for improved aquifer storage and recovery systems and associated methods.

SUMMARY

Certain embodiments of the disclosure pertain to systems and control methodologies for generating power when injecting water into an underground formation such as an aquifer, using equipment also configured to withdraw water out of the underground formation. The disclosed systems can be configured to adjust various operating parameters of any of various system components, such as the frequency of the drive signal provided to the electric motor, the flow rate through the well bore, the pressure in the well bore, the rotational speed of the motor, the drive signal voltage, the excitation voltage, etc., to maximize power generation under the prevailing flow conditions. In a representative embodiment, an aquifer storage and recovery system comprises a pump, an electric motor coupled to the pump, a drive unit configured to control operation of the electric motor, and a controller configured to flow water into a well bore from a source reservoir through the pump such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate as a generator. The controller can be further configured to determine a power output of the electric motor, determine a difference between the power output of the electric motor and a power output set point, and operate the drive unit to control a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the power output set point.

In any or all of the disclosed embodiments, operating the drive unit to control the rotational speed of the electric motor further comprises changing a frequency of a drive signal output by the drive unit to the electric motor.

In any or all of the disclosed embodiments, the controller is further configured to detect an increase in power output after changing the frequency of the drive signal, and store the increased power output as a new power output set point.

In any or all of the disclosed embodiments, the aquifer storage and recovery system further comprises a regeneration module connected to the drive unit and comprising inverter circuitry configured to convert direct current supplied to the drive unit from the electric motor to alternating current.

In any or all of the disclosed embodiments, a direct current (DC) bus of the regeneration module is connected to a DC bus of the drive unit.

In any or all of the disclosed embodiments, the aquifer storage and recovery system further comprises a down well flow control valve in the well bore, and the controller is configured to operate the down well flow control valve to maintain pressure in the well bore at a pressure set point.

In any or all of the disclosed embodiments, the down well flow control valve is coupled to a sleeve and coupled to a one-way valve, the one-way valve being disposed within the sleeve, the pump is disposed below the down well flow control valve and is in fluid communication with the sleeve, and the sleeve and the one-way valve are configured such that water flow into an aquifer flows through the sleeve to the pump and bypasses the one-way valve, and water flow out of the aquifer flows into the sleeve, through the one-way valve, and into the down well flow control valve.

In any or all of the disclosed embodiments, the controller is further configured to determine a first theoretical power output of the electric motor based at least in part on a flow rate through the well bore, a water level in the source reservoir, a pressure in the well bore, a numerical constant associated with the aquifer storage and recovery system, or any combination thereof, determine a difference between the first theoretical power output and a previously stored theoretical power output, and control the rotational speed of the electric motor based at least in part on the difference between the first theoretical power output and the previously stored theoretical power output.

In any or all of the disclosed embodiments, the controller is further configured to update the power output set point based at least in part on a change in the power output of the electric motor.

In any or all of the disclosed embodiments, the controller is further configured to determine a first rotational speed of the electric motor and the pump, and operate the drive unit to control the electric motor such that it rotates at a second rotational speed that is less than the first rotational speed.

In another representative embodiment, a pumped-storage hydroelectric system can include the aquifer storage and recovery system of any of the embodiments described herein.

In another representative embodiment, a method comprises pumping water from an aquifer into the source reservoir with the aquifer storage and recovery system of any of the disclosed embodiments, wherein the electric motor is powered with electricity supplied by a renewable energy power plant.

In another representative embodiment, a method comprises, with an aquifer storage and recovery system comprising a well bore, a pump in fluid communication with the well bore, an electric motor coupled to the pump, and a drive unit configured to control operation of the electric motor, flowing water into the well bore such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate the electric motor as a generator, determining a power output of the electric motor, determining a difference between the power output of the electric motor and a power output set point and, with the drive unit, controlling a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the power output set point.

In any or all of the disclosed embodiments, the method further comprises updating the power output set point based at least in part on a change in the power output of the electric motor.

In any or all of the disclosed embodiments, controlling the rotational speed of the electric motor further comprises varying a frequency of a drive signal output by the drive unit to the electric motor.

In any or all of the disclosed embodiments, the method further comprises detecting an increase in power output after changing the frequency of the drive signal and storing the increased power output as a new power output set point.

In any or all of the disclosed embodiments, flowing water into the well bore further comprises maintaining a pressure in the well bore at or above a pressure set point.

In any or all of the disclosed embodiments, the method further comprises, prior to determining the power output of the electric motor, determining a rotational speed of the electric motor, and with the drive unit, outputting a drive signal having a frequency matched to the rotational speed of the electric motor.

In any or all of the disclosed embodiments, the method further comprises reducing the frequency of the drive signal.

In any or all of the disclosed embodiments, the method further comprises determining a change in a theoretical power output of the aquifer storage and recovery system, and varying a frequency of a drive signal output to the electric motor by the drive unit.

In any or all of the disclosed embodiments, the method further comprises varying a position of a flow control valve disposed in the well bore to maintain a pressure in the well bore at a pressure set point.

In another representative embodiment, an aquifer storage and recovery system comprises a pump disposed in a well bore, an electric motor coupled to the pump, a drive unit configured to control operation of the electric motor, a down well flow control valve disposed in the well bore and in fluid communication with the pump, and a controller configured to flow water into the well bore from a source reservoir through the pump such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate as a generator. The controller is further configured to operate the down well flow control valve to maintain pressure in the well bore at a pressure set point, determine a power output of the electric motor, determine a difference between the power output of the electric motor and a power output set point, and operate the drive unit to control a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the power output set point.

The foregoing features and advantages of the disclosed technology will become more apparent from the following figures and detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic diagram of an aquifer storage and recovery system, according to one embodiment.

FIG. **2** is another schematic diagram of the aquifer storage and recovery system of FIG. **1** illustrating a hydraulic system for operating a down well flow control valve.

FIG. **3** is a single-line diagram of electrical components of the system of FIG. **1**, according to one embodiment.

FIG. **4** is a schematic block diagram of a representative embodiment of a control system.

FIG. **5** is a process flow diagram of a representative method of generating electricity with the system of FIG. **1**.

FIGS. **6** and **7** are schematic diagrams of an aquifer storage and recovery system connected to a renewable energy power plant, according to another embodiment.

FIGS. **8** and **9** are schematic diagrams of an aquifer storage and recovery system connected to a water source, according to another embodiment.

FIGS. **10** and **11** are schematic diagrams of an aquifer storage and recovery system configured for geothermal heating and cooling, according to another embodiment.

FIGS. **12** and **13** are schematic diagrams of the aquifer storage and recovery system of FIGS. **8** and **9** including a down well flow control valve configured to allow water injection and recovery through the same well bore.

FIG. **14** is a process flow diagram of a regeneration power output calculation method, according to one embodiment.

FIG. **15** is a process flow diagram illustrating another method of generating electricity with the system of FIG. **1**.

FIG. **16** is a schematic block diagram illustrating a representative computing environment in which any of the disclosed technologies can be implemented.

FIGS. **17-19** illustrate representative examples of down well flow control valves that can be used in combination with the systems described herein.

FIG. **20** is a cross-sectional view of a portion of a well bore illustrating an assembly including a down well flow control valve coupled to and received in a sleeve.

FIG. **21** is a magnified cross-sectional view of a portion of the coupling between the down well flow control valve and the sleeve in FIG. **20**.

FIG. **22** illustrates another embodiment of the assembly of FIG. **21** in which the down well flow control valve includes apertures disposed within the sleeve and outside of the sleeve.

DETAILED DESCRIPTION

Disclosed herein are systems and methods of generating electricity using aquifer storage systems and/or aquifer storage and recovery systems. Pump systems can be configured to recover ground water from an aquifer through a well bore for use in, for example, irrigation. During periods where water is available, the pump system can be used to pump/flow water back into the aquifer to "recharge" the aquifer for later use. During recharging, the pressure head developed in the well pipe(s) between the water reservoir/source and the aquifer can be used to generate electricity.

For example, in certain embodiments an aquifer storage and recovery (ASR) system can include a pump, a motor (e.g., an electric motor comprising a rotor and a stator) coupled to the pump, a drive unit or drive circuitry such as a variable frequency drive (VFD) configured to operate/drive the motor, and a controller. When water is withdrawn from the aquifer, the controller can operate the VFD to output a drive signal to operate the electric motor in a first direction. This, in turn, can drive the pump in the first direction to withdraw water from the aquifer through the well bore. When water is supplied to the aquifer, the pressure in the well column can cause the pump to rotate in a second, reverse direction, thereby causing the motor to rotate in the second direction. By controlling the voltage and/or frequency of the drive signal output by the VFD to the electric motor, the electric motor can be operated as a generator to generate electricity. The amount of power generated by the electric motor can also be controlled by varying the drive signal output by the VFD. The drive signal can be varied based on a variety of parameters associated with the ASR system, such as the flow rate, the water level in the supply reservoir, the pressure in the well column, one or more constants associated with the system, etc. In certain embodiments, the excitation voltage provided to the motor/generator can also be controlled.

In certain embodiments, the systems described herein can be configured to determine a theoretical power output of the electric motor based on one or more of the parameters above. In certain embodiments, the systems can be configured to initiate a routine to control/vary a drive signal of the VFD to optimize power generation by the electric motor when the theoretical power production varies from a previously stored theoretical power production value by greater than a specified threshold. For example, when a theoretical power production value at time T**2** based on any of the parameters above (e.g., as measured by sensors in the system) varies from a theoretical power production value previously determined at time T**1**, the system can control or vary the drive signal outputted by the VFD to establish a new power output set point.

The controller can take any combination of the steps outlined in the following examples to optimize/maximize the current induced in the windings of the electric motor. The controller can further operate the valves, the VFD, the pump, the motor, and/or the regeneration module to modify parameters of the generated current (e.g., the wave form, the voltage etc.,), and/or modify the amount of current/power generated, depending upon factors such as the flow rate through the well column, the pressure head in the well column, a set point corresponding to a specified power to be generated, etc., and deliver the power to a load or to an electric grid. In particular embodiments, the controller can adjust various parameters to maximize power generation while maintaining positive pressure in the well head. In certain embodiments, a pressure set point in the well column (e.g., at the well head) can be maintained regardless of flow rate (e.g., by operation of the down well flow control valve) while power generation occurs. This can prevent entrainment of air in the well column and subsequent injection of air into the aquifer, which can plug the aquifer.

In certain embodiments, the ASR systems and methods described herein can be used to provide pumped-storage hydroelectric generation capacity to store excess energy from renewable power sources such as photovoltaic cells and/or wind turbines when the power generated by the renewable sources exceeds demand. For example, during periods of relatively high renewable power production and relatively low power demand, the systems described herein can be operated to pump water from an aquifer into a storage volume or reservoir above (e.g., at a higher elevation than) the aquifer. During periods of relatively high power demand, the water can be reinjected into the aquifer to generate electricity and supplement the renewable power sources, which may have intermittent or cyclical periods of power production that do not necessarily coincide with periods of peak power demand. In certain embodiments, electricity produced using the system and methods described herein can be used to power loads (e.g., machinery) on the ASR system premises, and/or can be stored in a storage medium such as a battery, a heat sink, etc., for later use.

Example 1: Aquifer Storage and Recovery System

FIG. **1** schematically illustrates an exemplary aquifer storage and recovery (ASR) system **10**, according to one embodiment. As shown, the system **10** can comprise a well column/bore **12** extending from a surface side or ground surface to a subterranean reservoir or aquifer **13**. The well bore **12** can be in fluid communication with a water supply or reservoir **15**, which can be a surface water body such as a pond, lake, marsh, storage tank, etc., or a natural or manmade subterranean formation such as a shallow aquifer relatively close to the ground surface, a buried storage tank/volume, etc. The system **10** can further comprise an electric motor **16** at a first/upper end of the well bore **12** (e.g., above ground) and a pump **18** at a second/lower end of the well bore **12** (e.g., underground in the aquifer **13**) and coupled to the pump (e.g., by a drive shaft), although other configurations are possible. In certain embodiments, the pump **18** can be in fluid communication with the reservoir **15** by a conduit or pipe **30**. The well bore **12** can comprise a flow control device/valve **22** disposed in the well bore. The flow control valve can be located anywhere in the well column, for example below the pump **18**, above the pump **18**, at the lower end of the well column, at the top of the well column, etc. In the illustrated embodiment, the flow control valve **22** is located below the pump **18** and is referred to hereinafter as a down well flow control valve. The down well flow control valve **22** can be configured to control the flow rate into the aquifer though the well bore. In certain embodiments, the down well flow control valve **22** can be movable between a closed position (e.g., 0% open) and a fully open (e.g., 100% open), and can be continuously variable to any position therebetween to vary the flow rate through the well bore. FIGS. **17**-**19** illustrate representative embodiments of down well flow control valves that can be used in combination with the systems described herein.

In certain embodiments, the pump **18** can be any of various dynamic pumps such as a centrifugal pump, or any of various positive displacement pumps such as a piston pump, a peristaltic pump, a diaphragm pump, or a gear pump, to name a few. In particular embodiments, the pump **18** can be a centrifugal pump such as a turbine pump, for example a vertical turbine pump or a submersible turbine pump. The turbine pump can comprise one or a plurality of rotary pumping elements such as rotors or turbines.

The system **10** can also comprise motor drive circuitry, which in certain embodiments can be a drive unit configured as a variable frequency drive (VFD) **20**. The VFD **20** can be configured to produce/output a drive signal to the electric motor **16** to drive the pump **18** when operating in a pumping mode, and to operate the electric motor as an electric generator in a generating mode/regenerating mode when the pump is driven by water pressure in the well column, as further described below.

In certain embodiments, the system **10** can include additional power electronics such as inverters, rectifiers, pulse width modulation (PWM) control modules, etc. For example, in certain embodiments the system **10** can comprise regeneration circuitry schematically illustrated as a regeneration module **25**. In certain embodiments, the regeneration module **25** can comprise rectifier circuitry configured to convert direct current (DC) to alternating current (AC) for transmission to an electrical source generally indicated at **34**, such as an electric utility. In certain embodiments, the regeneration module **25** can be connected to the VFD **20**, for example, by a common DC bus. The regeneration module **25** is described in greater detail with reference to FIG. **3** below.

The system can be operable in a pumping mode to withdraw water from aquifer **13** and in a regeneration mode to generate power by injecting water into the aquifer. In certain embodiments, the system **10** can comprise a control module/controller/programmable logic controller (PLC) indicated schematically as a controller **32** in communication with the VFD **20** and/or the regeneration module **25**. The controller **32** can be configured to transmit control signals to the VFD **20**, the motor **16**, the regeneration module **25** and/or other components of the system to direct/control operation of the system in the pumping mode and in the regeneration mode.

As noted above, in certain embodiments the VFD **20** and/or the regeneration module **25** can be connected to the electrical source **34**, and can be configured to draw power from the electrical source **34** or supply power to the electrical source **34** depending upon whether the system is operating in the pumping mode or the regeneration mode. In certain embodiments, the electrical source **34** can also be an electrical load (e.g., machinery such as an electric motor, etc.) or an energy storage system such as a battery.

In certain embodiments, the controller **32** can be in communication with a variety of sensors, transducers, and/or actuators, which can provide data to the controller and/or allow the controller to actuate elements of the system such as valves, etc. The sensors/transducers/actuators can be above ground, underground, in the well column **12**, and/or in one or more separate well bores in communication with the aquifer **13**. For example, FIG. **2** schematically illustrates a particular implementation of the system **10** which includes a second well bore **36** separate from the well bore **12** and configured as a monitoring well. An aquifer level/water level transducer **38** can be disposed in the well bore **36**, and can be configured to transmit data of the water level in the aquifer **13** to the controller **32**. A second water level transducer **40** can be located in the well bore **12**, for example, adjacent the down well flow control valve **22**. In certain embodiments, the controller **32** can be configured to compare the water level in the aquifer as measured by the transducer **40** with the water level measured by the transducer **38**, which can be isolated from the effects of water entering or exiting the aquifer through the well bore **12**, to determine the overall water level in the aquifer **13**.

The system **10** in FIG. **2** can further comprise a pressure sensor schematically shown at **42** located in the well bore **12**. The pressure sensor **42** can be configured to transmit data of the water pressure in the well bore **12** to the controller **32**. The pressure sensor **42** can be located above the pump **18**, at the level of the pump **18**, below the pump **18**, and/or above, below, or at the level of the down well flow control valve **22**. In certain embodiments, the system **10** can comprise multiple pressure sensors at any combination of these locations, or at all of these locations, depending upon the particular requirements of the system.

The system **10** can also include a hydraulic system **44** configured to control the position of the down well flow control valve **22**. For example, in the illustrated embodiment the hydraulic system **44** can comprise a hydraulic fluid reservoir **46** in fluid communication with two hydraulic pistons **48** and **50**. The hydraulic pistons **48** and **50** can be controlled (e.g., by the controller **32**) to provide pressurized hydraulic fluid to the down well flow control valve **22** to control the position of the down well flow control valve. A hydraulic actuator motor **52** can pressurize the hydraulic fluid, which can be distributed to the pistons by a valve block indicated at **53**. Pressure transducers **54** and **56** can determine the pressure of the hydraulic fluid supplied to the pistons **48** and **50**. The position of the pistons **48**, **50** can be determined by one or more linear potentiometers or other transducers such as potentiometer **58**. In certain embodiments, the controller **32** can determine a position of the down well flow control valve **22** based at least in part on the position of the hydraulic pistons as indicated by the linear potentiometer **58**, the pressure of the hydraulic fluid as indicated by the pressure transducers **54** and **56**, etc. Data from the various sensors, transducers, etc., can be transmitted via various application interfaces to the controller **32**, which can have a supervisory control and data acquisition (SCADA) architecture indicated at **61**.

The controller **32** can also be in communication with a variety of sensors associated with the electric motor **16** and/or the VFD **20**, such as voltage and/or current sensors. The controller **32** can be configured to control operation of the various components of the system such as the VFD **20**, the electric motor **16**, the down well flow control valve **22**, various ancillary pumps and valves, etc., based at least in part on data provided by one or more of the sensors above to vary power production by the electric motor in the generating mode, as further described below.

In certain embodiments, the electric motor **16** and associated components can be configured as a three-phase system (however, the system can include any number of phases). FIG. **3** illustrates a single-line diagram of the electrical connections between selected components of the system **10**. Beginning at the left side of FIG. **3**, an electric connection line **60** to the electric source/utility **34** can pass through a fuse **62** to a transformer **64** (e.g., a high/medium voltage to low voltage transformer) (e.g., 600 VAC or less). A utility meter **66** can be connected to the electrical line **60** between the transformer **64** and a main disconnect **68**. In certain embodiments, the main disconnect **68** can be a circuit breaker with long time, short time instantaneous trip settings and ground (LSIG) fault protection. In certain embodiments, the main disconnect **68** can comprise a phase and/or voltage monitoring relay **70**. A control transformer **72** (e.g., 480 VAC to 120/240 VAC) can be connected in parallel with the VFD **20**. The VFD **20** can be connected to the line **60** in series with a fuse **74** and a disconnect/circuit breaker **76** (e.g., with LSI or LSIG settings).

As noted above, the electric motor **16** can be connected to the VFD **20**. In the illustrated embodiment, the VFD **20** can comprise an AC-DC rectifier module **78** connected to a DC bus indicated at **80**. In certain embodiments, the DC bus **80** can comprise a plurality of capacitors. The DC bus **80** can be connected to a PWM module **82**, which can provide current to the motor **16** at the selected output frequency of the VFD **20**.

The regeneration module **25** can comprise a DC-AC inverter module **84** with inverter circuitry connected to a DC bus **86**. The DC bus **86** of the regeneration module **25** can be connected to the DC bus **80** of the VFD **20**. The inverter module **84** can be connected to the line **60** in parallel with the rectifier module **78** of the VFD **20**.

Example 2: Control Diagram

FIG. **4** is schematic block diagram of a representative control system for implementing the power generation methods described herein when the system is operating in the regeneration mode. At block **102**, a power output set point can be provided. In certain embodiments, the power output set point **102** can be an actual power output of the electric motor **16** operating in the regeneration mode. The power output set point **102** can be provided to a proportion-integral-derivative (PID) control module **118**, which can be configured to apply one or more of proportional, integral, and/or derivative control (referred to herein as "PID control") to the output frequency/drive signal of the VFD **20**. The power output **120** generated by the electric motor **16** can be determined and transmitted to a power output comparison module **116**, which can be in communication with the PID control module **118**. The power comparison module **116** can be configured to determine whether a current power output of the electric motor **16** in the regeneration mode is less than, equal to, or greater than the power output set point **102**. In certain embodiments, when the power output comparison module **116** determines that the current power output of the electric motor is greater than the power output set point **122**, the current power output can be the maximum power output **122** of the electric motor **16** under the flow conditions, and the maximum power output **122** can be stored as a new power output set point as described in greater detail below.

The power output set point **102** can also be provided to a theoretical power calculation module **104**. The theoretical power calculation module **104** can determine/calculate a theoretical power output of the electric motor **16** based at least in part on a variety of parameters including one or more of a flow rate **106**, a water level **108** (e.g., in the reservoir **15**), a pressure **110** (e.g., in the well column **12**), the height of the well column, the density of the liquid, and/or a numerical constant **112** associated with the system **10**. For example, in certain embodiments the theoretical power output can be determined with the following equation, where the constant can be the numerical constant **112**. The various parameters can be provided by one more of the sensors and/or transducers described above with reference to FIG. **2**.

$$\text{Theoretical Power Output} = \frac{1}{2}\frac{\text{Flow Rate} \times \text{Total Dynamic Head}}{\text{Numerical Constant}}$$

In certain embodiments, the total theoretical power (e.g., horsepower) of the system can be calculated by multiplying the flow rate by the total dynamic head of the system, and dividing by the system constant **112**. In certain embodiments, the total dynamic head can be determined by adding the static height (also known as the discharge head) of the well column pipe, the static lift (also known as the suction head) of the pump, and the friction loss or head loss of the well column pipe.

In certain embodiments, the theoretical power calculation module **104** can be configured to recalculate/determine the theoretical power output of the system periodically after the passage of a specified time period (e.g., 5 seconds, 10 seconds, 30 seconds, 1 minute, 3 minutes, 5 minutes, 10 minutes, etc.), and/or upon detecting a change in one or more of the input parameters. The module **104** can transmit the theoretical power output values to a theoretical power output comparison module **114**, which can compare a most recent theoretical power output with one or more earlier theoretical power outputs. The power output comparison module **116** can be in communication with the theoretical power comparison module **114**. In certain embodiments, when the theoretical power output module **114** determines that the theoretical power output of the electric motor has changed, this data can be provided to the power output comparison module **116**, which can check whether the current power output is greater than the power output set point and initiate variation/control of the drive signal by the PID control module **118**.

Example 3: Regeneration Mode Operation of ASR System

Referring again to FIG. **1**, during pumping operation (e.g., in the pumping mode), the VFD **20** can operate the electric motor **16** to drive the pump **18** in a first direction or pumping direction to pump water out of the well or aquifer **13**, as shown by arrows **26**. Rotation of the electric motor **16** in the first direction is indicated by arrow **27** in FIG. **3**. Electric current from the utility **34** can be provided to the electric motor **16** via the VFD **20**, which can output a drive signal at a specified voltage, current, and/or frequency to the motor.

During recharging or storage operation (e.g., in the regeneration mode), water from the reservoir/source **15** can be fed back into the aquifer **13** through the well column **12**, as indicated by arrows **28** in FIG. **1**. In certain embodiments, the pressure in the well bore **12** can be sufficiently high to operate/rotate the pumping elements of the pump **18** in a second direction or reverse direction indicated by arrow **29** in FIG. **3**. Rotation of the pumping elements can cause corresponding rotation of the rotor of the electric motor **16**, which can induce an electric current in the stator of the motor **16**. By adjusting one or more of the frequency, voltage, and/or current of the drive signal applied to the stator by the VFD **20**, electric current (e.g., direct current) can be developed or generated in the VFD **20** (e.g., on the DC bus **80**). The inverter **84** of the regeneration module **25** can then convert the DC current to alternating current (AC) for transmission to, for example, the power utility **34**. In certain embodiments, the power supplied to the power utility **34** can be measured/recorded by the meter **70** (FIG. **3**). In certain embodiments, the generated power can be stored for later use (e.g., in a battery, heat sink, or other energy storage media). In certain embodiments, the generated power can be used to power other loads (e.g., electric motors/pumps or other machinery).

FIG. **5** illustrates a representative method of operating the system **10** in the regeneration mode to generate electricity when supplying water to the aquifer **13**. At process block **202**, the controller **32** can close the down well flow control valve (e.g., down well flow control valve **22**) by transmitting control signals to pressurize the hydraulic circuit/system **44** (FIG. **2**). After the controller **32** determines that the down well flow control valve **22** is fully closed, it can transmit control signals to open a source water supply valve at the well head at process block **204**. This can provide water to the well bore **12**, pressurize the well bore, and force out any air in the well bore pipe. At process block **206**, when the controller **32** determines that the water flow going into the well bore has stopped and the pressure in the well bore has reached a set point, the controller **32** can transmit control signals to the hydraulic system **44** to open the down well flow control valve **22** to allow water to flow into the aquifer at a target flow rate. The target flow rate or flow rate set point can be programmed by an operator, or selected by the controller **32** based on one or more criteria, such as maintaining positive pressure (e.g., pressure greater than atmospheric pressure, greater than 0 psi, etc.) at the top of the well head. In certain embodiments, maintaining positive pressure in the well bore can prevent entrainment of air in the water flowing through the well bore, which can plug the aquifer.

As water flows through the pump **18** into the aquifer **13**, it can cause the pump bowls/pumping elements to turn in the second/reverse direction (arrow **29** in FIG. **3**). At process block **208**, once the controller **32** determines that water is flowing through the well bore **12** at the flow rate set point and that the pressure in the well column is at the pressure set point, the controller can determine the rotational speed (e.g., RPM) of the electric motor **16** (e.g., of the rotor). At process block **210**, the controller **32** can transmit control signals to the VFD **20** to output a drive signal having a frequency that matches or corresponds to the rotational direction and speed of the electric motor **16**. Thus, in certain embodiments the controller **32** can command the VFD **20** to turn in the reverse direction and at the same speed/frequency as the electric motor **16**.

At process block **212**, the controller **32** can transmit control signals to the VFD **20** to output a drive signal at a lower rotational speed/frequency than a natural/unloaded rotational speed/frequency of the pump at the selected flow rate and pressure. For example, the controller **32** can command the VFD **20** to output a drive signal with a frequency that is lower than the rotational speed/frequency at which the pump **18** would otherwise drive the electric motor **16** under the flow conditions. This can create a load on the pumping elements such that the pump operates as a water turbine, resulting in electric current generation in the windings of the electric motor **16**.

In certain embodiments, the controller **32** can vary any of a variety of parameters of the system to maximize power output, such as the flow rate, pressure, rotational speed of the pump, the frequency of the VFD drive signal, etc. For example, referring to FIGS. **4** and **5**, in the illustrated embodiment the controller **32** can determine a first power output/actual power output (e.g., watts or kilowatts) of the electric motor **16** at process block **214**, and store it in a memory. In certain embodiments, the initial power output can be stored as the initial power output set point **102** (FIG. **4**). At process block **216**, the power output of the electric motor **16** can be provided to the PID control module **118**, which can apply any of proportional, integral, and/or derivative control to increase or decrease the frequency of the drive signal output by the VFD **20**.

At process block **218**, the power output comparison module **116** can determine a difference between the power output of the electric motor **16** and the power output set point **102**. For example, in certain embodiments the power output comparison module **116** can determine whether the power output of the electric motor **16** is higher or lower than the power output set point **102**, as illustrated in FIG. **5**. In certain embodiments, the power output comparison module **116** can determine a numerical difference between the power output of the electric motor **16** and the power output set point **102**. Based at least on the difference, which can include the determination that a difference exists, the controller **32** can control/vary the drive signal (e.g., vary the frequency of the drive signal) output by the VFD **20** and measure/determine the power output of the electric motor with the modified drive signal. In the illustrated embodiment, if the power output is lower, this information is provided to the PID control module **118** as feedback and the drive signal frequency is varied accordingly. If the power output is higher than the power output set point **102**, the increased power output is stored as a new power output set point at block **220** (e.g., the power output set point is updated), and the routine returns to process block **214**.

Meanwhile, the controller **32** can execute a parallel routine at process blocks **222** and **224**. At process block **222**, the theoretical power calculation module **104** can determine a theoretical power output of the electric motor **16** based at least in part on, for example, the flow rate **106** through the well column **12**, the water level **108** in the reservoir **15** and/or in the aquifer **13**, the pressure **110** in the well bore **12**, and/or the numerical constant **112** associated with the system **10**, and store the theoretical power output in a memory. The theoretical power calculation module **104** can update the theoretical power output based on data of the various parameters above. For example, the theoretical power calculation module **104** can determine a second theoretical power output, such as after the passage of a specified time period (e.g., 5 seconds, 10 seconds, 30 seconds, 1 minute, 3 minutes, 5 minutes, 10 minutes, etc.). The theoretical power comparison module **114** can then compare the second theoretical power output with the first (previously stored) theoretical power output and determine whether the second theoretical power output varies from the first theoretical power output by a specified threshold/amount (e.g., 1%, 2%, 3%, 5%, 10%, etc.). If the second theoretical power output does not differ from the first theoretical power output by the specified threshold, the controller **32** can retain the power output set point **102** in the memory, and returns to process block **214** (e.g., indicating that the current power output is at or near the maximum power output for the flow conditions). If the second theoretical power output differs from the first theoretical power output by the specified threshold or more, the controller **32** can proceed to process block **218** and adjust the drive signal.

This process can be repeated as the aquifer **13** fills and the reservoir **15** drains. In certain embodiments, the power output set point **102** can be reset, either as a VFD drive signal frequency is determined that results in power output (e.g., maximum power output **122**) that is higher than the current set point, or as flow conditions change as determined by input from the various sensors and/or the theoretical power output calculation module **104**.

Referring again to FIG. **3**, as the controller **32** executes the routine above, the power generated in the windings of the electric motor **16** can be placed onto or transmitted to the DC bus **80** of the VFD **20**. The electricity can then flow to the DC bus **86** of the regeneration module **25**, which can be connected to the DC bus **80** of the VFD **20**. The inverter module **84** of the regeneration module **25** can then convert the DC current from the DC bus **86** to AC current and supply the alternating current to the utility **34** (or to another load).

In certain examples, the controller **32** can also adjust other parameters instead of, or in addition to, the drive signal frequency. For example, in certain embodiments the controller **32** can vary one or more of the flow rate through the well bore, the pressure in the well bore, the rotational speed of the motor, the drive signal voltage, the excitation voltage provided to the motor windings, etc., and determine the power output of the motor. The controller **32** can iteratively adjust one or more of the parameters above and determine if a change produces more or less power. For example, if the controller **32** determines that by allowing the motor to spin faster more power is produced, then the controller can repeat the test by incrementing one or more parameters (e.g., flow rate, pressure, rotational velocity, voltage, frequency, etc.) to see if the same result occurs again. This power output determination and parameter adjustment process can run in a continuous loop seeking maximum power production and/or a selected power generation target.

In other embodiments, the controller **32** can vary the frequency of the VFD drive signal (or any of the parameters described herein) when the actual/instantaneous power output of the electric motor falls below the power output set point by a specified threshold. In yet other embodiments, the controller **32** can determine a difference between the theoretical power output and the actual power output of the electric motor, and vary the VFD drive signal (or any of the other parameters described herein) as described above to reduce the difference between the theoretical power output and the actual power output (e.g., to try to generate the theoretical power output).

Example 4: Energy Storage Applications of ASR

The ASR systems and methods described herein can be used in a variety of settings/applications to generate and/or store electrical energy, and/or store thermal energy. For example, in certain embodiments ASR systems and the control methods described herein can be used in combination with power plants, such as renewable power plants/sources including wind turbines/wind farms, photovoltaic cells/power stations such as solar farms, etc., to store energy when electrical power production exceeds demand. Such systems can be known as aquifer pumped-storage hydroelectric systems, or "aquifer pumped hydro" (APH) systems. Energy can be stored by using the electrical power from a renewable power plant to pump water from a relatively deep aquifer into a storage reservoir, such as a relatively shallow alluvial well/aquifer, a natural or manmade above-ground or underground reservoir, etc. During periods where power demand exceeds production from the renewable power plant, energy can be recovered by injecting water from the reservoir into the deep aquifer and operating the pump/motor combination in the regeneration mode as described herein to generate electricity.

For example, FIG. **6** illustrates an aquifer pumped-storage hydroelectric system **300** similar to the system **10** including a first electric motor **302** and pump **304** in fluid communication with a reservoir **306** in the form of a relatively shallow alluvial well/aquifer (can also be a manmade or natural above-ground or underground storage). The system **300** further comprises a second electric motor **308** and pump **310** in fluid communication with a relatively deep aquifer **312** via a well bore, as described above. A pipe or conduit **314** can interconnect the wells between aquifers **306** and **312**. A VFD **316** can be coupled to the electric motor **302**, and a VFD **318** can be coupled to the electric motor **308**. A regeneration module **320** can also be connected to the VFD **316** and the VFD **318**. The VFDs can be electrically connected to a power source such as a utility (e.g., utility transmission lines), and/or to a power plant, such as a renewable energy power plant **322**, which can include any of various renewable power sources including wind turbines, photovoltaic/solar cells, etc.

FIG. **6** shows the direction of electric power and water flows during injection of water into the deep aquifer **312**. As water is withdrawn from the shallow aquifer **306** and injected into the aquifer **312** as indicated by arrows **324**, the electric motor **308** can be operated in the regeneration mode according to any of the methods described herein. Electric power generated by the electric motor **308** can be supplied to the power source **322** (e.g., to a utility) as indicated by arrows **326**, and/or used to run the electric motor **302** as indicated by arrow **328**. Power generation by the electric motor **308** can be optimized using any of the routines described herein. Referring to FIG. **7**, during periods when electrical power production from the renewable power source exceeds power demand, the extra power **330** can be used to pump water from the deep aquifer **312**. The water can be returned to the reservoir/shallow aquifer **306** as indicated by arrows **332**, and/or supplied to water consumers through a conduit **334**.

FIGS. **8** and **9** illustrate another embodiment of a system **400** where water from a water source such as a fresh water or wastewater treatment plant **402** is stored in an aquifer **404**. An electric motor **406**, pump **408**, VFD **410**, and regeneration module **412** can operate as described herein to produce electricity, which can be consumed by the water treatment plant **402** and/or supplied back to the power grid **414**. When treated water is needed, the water can be recovered from the aquifer **404** as indicated in FIG. **9** and supplied to water consumers.

FIGS. **10** and **11** illustrate another embodiment of a system **500** where water is withdrawn from a first, cold aquifer **502**, passed through a heat exchanger **504** (e.g., a water to air heat exchanger), and stored in a second, warm aquifer **506**. FIG. **10** illustrates operation in a cooling mode in which cold water is withdrawn from the cold aquifer **502**, passed through the heat exchanger **504** to provide cooling (e.g., to a building, premises, campus, district, etc.), and injected into the warm aquifer **506**. The pump **508**, electric motor **510**, VFD **512**, and regeneration module **514** can operate in the regeneration mode as described herein to generate electricity, which can be used to power the electric motor **516** and the pump **518** of the cold aquifer **502**. FIG. **11** illustrates flow in the reverse direction, where warm water is withdrawn from the warm aquifer **506**, passed through the heat exchanger **504** to provide heating, and injected back into the cold aquifer **502**, during which the electric motor **516**, a VFD **520**, and a regeneration module **524** can generate electric power. Additional power can be supplied to/from a utility grid **522**. In certain embodiments, the warm and cold aquifers can be different regions of the same underground formation spaced apart sufficiently so as to be thermally isolated from each other.

FIGS. **12** and **13** illustrate another embodiment of the system **400** including a down well flow control valve **416** and a submersible pump and motor assembly configured to allow water injection and water recovery from the aquifer **404** through the same well bore. In the configuration illustrated in FIGS. **11** and **12**, the down well flow control valve **416** is coupled to a well column pipe **418**. The down well flow control valve **416** is in fluid communication with a pump **420** coupled to the lower end of the down well flow control valve **416**. A submersible electric motor **422** can be coupled to the lower end of the pump **420**. The submersible electric motor **422** can drive the pump **420** to pump water up the well column pipe when operating in the pumping mode, and water pressure can drive the pump in the manner of a turbine to operate the submersible electric motor as a generator in the regeneration mode, as described above.

In certain embodiments, when operating in the regeneration mode, the down well flow control valve **416** can be configured to direct water flow through the pump **420**, and/or through the pump **420** and around or outside the pump directly into the aquifer. For example, in certain embodiments the down well flow control valve **416** can comprise a plurality of apertures arranged in discrete groups separated along the length of the valve body, such as shown and described with reference to FIG. **22**. When the down well flow control valve is between 1% and 50% open, water can flow through a first group of apertures into the pump **420**, and the submersible electric motor **422** can spin to generate electricity. When the down well flow control valve **416** is 51% to 100% open, water can flow through the first group of apertures into the pump, as well as through a second group of apertures arranged such that the water flow through the second group of apertures bypasses the pump. Accordingly, the submersible electric motor **422** can spin to produce electricity, and water can simultaneously be injected directly into the aquifer without flowing through the pump **420**. When the down well flow control valve is 100% closed, the electric motor **406** can be driven in the opposite direction to pump water out of the aquifer, as described further below with reference to FIGS. **20-22**.

Example 5: Further Regeneration Mode Operation

In another representative embodiment, the controller **32** can operate as follows. The controller **32** can check to see if the down well control valve (e.g., valve **22**) is fully closed by pressurizing the closed hydraulic circuit/system **44** (FIG. **2**). After the controller determines that the valve **22** is fully closed, it can open the source water supply valve at the well head. This can provide water and pressure into the well column **12** and force out air in the well column pipe. When the controller determines that the flow going into the well has stopped and the pressure in the well column has reached a set point, it proceeds to the next step.

In certain embodiments, the next stage can be for the down well control valve **22** to slowly open to allow for the water to start to flow into the aquifer at the target flow rate. The target flow rate or flow rate set point can be programmed by an operator, or selected by the controller **32** based on one or more criteria, such as maintaining positive pressure at the top of the well head. As water flows through the pump **18** backwards it causes the pump bowls/pumping elements to also turn in the reverse direction. Once the controller **32** determines that the target flow and pressure are being met, it can determine at what speed (e.g., RPM) that the motor rotor is spinning, and can command the VFD **20** to turn in that same reverse direction and at the same speed/frequency. The controller **32** can then transmit commands/control signals to the VFD **20** to run at a lower rotational speed/frequency than a natural/unloaded rotational speed/frequency of the pump **18** at the selected flow rate/pressure, e.g., lower than the rotational speed/frequency at which the water would otherwise drive the pump bowls/pumping elements, causing the excess energy to be placed onto the DC bus **80** (FIG. **3**) of the VFD **20**. The regeneration module **25** connected to the DC bus can then convert the DC power to AC power and supply that energy back onto the AC grid (or to another load).

The controller **32** can then determine the energy output (e.g., watts) being produced and maximize it by continually adjusting the reverse direction speed of the electric motor **16** to maximize power production. The speed of the motor **16** can be controlled by varying the voltage and/or frequency of the drive signal applied by the VFD **20**. If the controller **32** slows the electric motor **16** down too much, the power production will then be less than it was when it was last checked. The controller **32** can then speed the electric motor **16** back up slightly (e.g., by increasing the frequency of the drive signal) to determine if that change produces more or less power, and continue to adjust. If the controller **32** determines that allowing the electric motor **16** to spin faster produces more power, then it can repeat the test by incrementing one or more parameters (e.g., flow rate, pressure, rotational velocity, drive signal voltage, drive signal frequency, etc.) to see if the same result occurs again. The controller **32** can run this energy check and VFD speed readjust process in a continuous loop, or at selected time intervals, to maximize power production and/or to operate at a selected power production level.

In certain embodiments, using the down well control valve **22** to maintain positive well head pressure and a constant flow rate, along with the controller program that is continually sensing and adjusting parameters to produce maximum power, can provide significant advantages, such as increased electricity generation, as compared to existing ASR generation systems.

Example 6: Rate of Return and Theoretical Power in Regeneration Mode Operation

In another exemplary embodiment, the control logic can be written in two executable routines that can be utilized on, for example, Allen Bradly—Rockwell Automation PLC controllers utilizing Studio5000 or RSlogix5000 programming software. The programs can be written utilizing advanced UDT's (User Defined Tags) to facilitate implementation into established existing PLC systems. The logic can also be converted to other PLC controllers if desired.

In certain embodiments, the first routine can be a regeneration power calculation program, and the second routine can be a regeneration tune calculation program. The first routine can be configured to calculate (using, for example, a theoretical generated electricity quantity based on the injection flow and well head pressure) a "rate of return" count down for the user that alerts the user to the point at which an initial capital investment (e.g., to purchase and install the system) would be paid off. The second routine can be configured to 'tune' the system by varying any of various operational parameters to maximize/optimize electricity generation for a given set of operating conditions.

Referring to FIG. **14**, as noted above the first routine can be a regeneration power calculation program. In certain embodiments, using mathematical equations and in combination with injection flow, well head pressure and/or aquifer level a theoretical generated power (e.g., horsepower or kW) can be calculated. At process block **602**, a user can input (e.g., using an HMI screen or other interface) the total capital investment cost and the utility power cost. At process block **604**, if a regeneration module is not installed, the first routine can, at process block **606**, calculate a theoretical horsepower/torque generated (e.g., by the pump) and, at block **608**, calculate a theoretical power generated by the regeneration module during the injection process. At process block **610**, the routine can display a theoretical "rate of return" countdown based on the theoretical horsepower/torque and the theoretical power generated and, at block **612**, can alert the user when the initial capital investment could have been paid off if they had installed ASR power regeneration with the use of control functionality/logic as described herein.

Referring again to block **604**, if a regeneration module is installed, the controller can determine the real/actual horsepower and/or torque from the motor starter/VFD at block **614**. At block **616**, the controller can determine the power output generated by the electric module (e.g., from the regeneration module). Based on the horsepower/torque and the power generated, at block **618** a rate of return countdown can be displayed and, at block **620**, the system can alert the user when the initial capital investment has been paid off by the electricity generated using the ASR power regeneration system. In certain embodiments, the actual power generated can be determined from a meter (e.g., meter **70** of FIG. **3**) and displayed to the user during regeneration operation.

Referring to FIG. **15**, the second routine can be a regeneration mode tuning or calculation program. For example, at process block **702** the controller can transmit control signals to flow water into the well column. At process block **704**, during the initial startup of the injection process (e.g., while water is flowing into the well column from the reservoir) the controller can store a maximum power value (e.g., kW) generated by the electric motor as determined from the regeneration module. At process block **706**, as the injection process proceeds the controller can continuously monitor the power supplied from the regeneration module. At process block **708**, if the current power equals the maximum power value, then the controller can continue to monitor the power as at block **706**. However, if the current power does not equal the stored maximum power value, then the controller can initiate a VFD adjusting routine or tuning routine at process block **710**, in which the frequency of the drive signal is varied according to any of the embodiments described herein. For example, the stored maximum power value can be used as a set point value for a PID tuned control loop. In certain embodiments, the VFD feedback speed in Hz (e.g., the frequency of the drive signal) can be scaled for use in the PID tuned loop. The controller can also calculate a theoretical horsepower/torque as described above. A first value, in one example 99% of the theoretical horsepower, and a second value, in one example 101% of the theoretical horsepower, can be calculated by the controller.

In certain embodiments, if the calculated theoretical horsepower changes (e.g., in relation to a change in flow, level, and/or pressure) or drops below the first value (e.g., 99% of the theoretical horsepower), a zero can be moved into/substituted for the maximum power stored value, and on the next scan/execution of the program loop a new maximum power value can be stored. In certain embodiments, this logic can be fail-safe logic to protect the electric motor and VFD/regeneration module from dramatic changes in flow and/or pressure.

If the calculated theoretical horsepower changes (e.g., in relation to a change in flow, level, or pressure) or rises above the second value (e.g., 101% of the theoretical horsepower), a zero can be moved into/substituted for the maximum power stored value, and on the next scan/execution of the loop a new maximum power value can be stored. This logic can also protect the electric motor and/or VFD/regeneration module from dramatic changes in flow and/or pressure.

In certain embodiments, if the scaled VFD feedback signal is above a selected first constant value in the programming (e.g., 8192 in one particular embodiment), then the controller can slow the VFD drive signal speed/frequency and can stop adjusting the VFD drive signal speed/frequency when the VFD scaled feedback signal is at the first constant value. If the scaled VFD feedback signal is at or below a selected second constant value (e.g., 8191 in one particular embodiment), then the PID tune loop will speed up the VFD speed and will stop adjusting the VFD speed when the VFD scaled feedback signal is at the second constant value. This can correlate with maximum power by the electric motor under the flow conditions. The maximum power generated can be stored as a maximum power value at **712** and the program routine can start over at **706** with the controller monitoring the power generated.

Example 7: Example Computing Environment

FIG. **16** and the following discussion are intended to provide a brief, general description of an exemplary computing environment in which the disclosed technology may be implemented. For example, the methods and processes described herein can be carried out by a controller or processor configured similarly to the computing environment described below. Moreover, the disclosed technology may be implemented with other computer system configurations, including hand held devices, digital signal processors (DSPs), multiprocessor systems, microprocessor-based or programmable consumer electronics, network PCs, minicomputers, mainframe computers, and the like. The disclosed technology may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network.

With reference to FIG. **16**, an exemplary system for implementing the disclosed technology includes a general-purpose controller in the form of an exemplary PC **800**, including one or more processing units **802**, a system memory **804**, and a system bus **806** that couples various system components including the system memory **804** to the one or more processing units **802**. The system bus **806** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. The exemplary system memory **804** includes read only memory (ROM) **808** and random-access memory (RAM) **810**. A basic input/output system (BIOS) **812**, containing the basic routines that help with the transfer of information between elements within the PC **800**, is stored in ROM **808**. In the example of FIG. **16**, processor-executable instructions for controlling the motor, the VFD, the valves, the regeneration module, and operational modes of the system can be stored in a memory **810**A, and data such as set points (e.g., current, voltage, flow rate, pressure, etc.) can be stored in memory **810**B.

The exemplary PC **800** further includes one or more storage devices **830** such as a hard disk drive for reading from and writing to a hard disk, a magnetic disk drive for reading from or writing to a removable magnetic disk, and an optical disk drive. Such storage devices can be connected to the system bus **806** by a hard disk drive interface, a magnetic disk drive interface, and an optical drive interface, respectively. The drives and their associated computer readable media provide nonvolatile storage of computer-readable instructions, data structures, program modules, and other data for the PC **800**. Other types of computer-readable media which can store data that is accessible by a PC, such as magnetic cassettes, flash memory cards, digital video disks.

A number of program modules may be stored in the storage devices **830** including an operating system, one or more application programs, other program modules, and program data. A user may enter commands and information into the PC **800** through one or more input devices **840** such as a keyboard and a pointing device such as a mouse. A monitor **846** or other type of display device is also connected to the system bus **806** via an interface, such as a video adapter. Outputs such as commands, drive signals, etc., can be transmitted via one or more output devices **845**.

The PC **800** may operate in a networked environment using logical connections to one or more remote computers, such as a remote computer **860** including a memory **862**. In some examples, one or more network or communication connections **850** are included. The remote computer **860** may be another PC, a server, a router, a network PC, or a peer device or other common network node, and typically includes many or all of the elements described above relative to the PC **800**, although only a memory storage device **862** has been illustrated in FIG. **16**. The personal computer **800** and/or the remote computer **860** can be connected to a logical a local area network (LAN) and a wide area network (WAN). In certain embodiments, the remote computer **860** can comprise a virtual processor implemented in a remote server environment or cloud computing environment. In certain embodiments, the systems and/or controllers described herein can be managed controlled/remotely through a remote or cloud computing platform, and/or can provide data to or retrieve operational settings from the remote computing platform.

Example 8: Exemplary Down Well Flow Control Valves

FIGS. **17-19** illustrates representative examples of down well flow control valves that can be used in combination with any of the ASR systems described herein. FIG. **17** illustrates an exemplary well column **900** including upper casing section **922**, intermediate casing section **924**, and lower casing section **926**, and comprising a down well flow control valve **902** (shown in an open position) that selectively allows liquid to flow from an upper aquifer or reservoir **904** to a subterranean aquifer **906** via a liquid flow passageway **905** having opening **907**, as indicated by arrows **908**. Liquid indicated by arrows **908** that is being pumped into well column **900** flows downwardly into the valve assembly **902**, outwardly through apertures **910**, upwardly between the well casing **912** and bore hole **914** to and into the upper reservoir **904**. When the down well flow control valve **902** is in a closed position (e.g., with valve member **916** covering apertures **910**) the lower apertures **918** provide a bypass passageway permitting the flow of liquid through the valve assembly **902** from the exterior of conduit **920**, through apertures **918** to the interior of conduit **920** and to or from the intermediate and lower casing sections **924**, **926** of the well column **900** where the liquid can be delivered to the lower aquifer **906**. The valve **902** can be moved into a 'shut-off' position, wherein valve member **916** overlies and closes the apertures **910** and wherein a second valve member or plug **928** closes the apertures **918** and the interior passageway through the conduit section **920**. As a result, liquid cannot flow to or from apertures **910** or through the conduit to or from the lower section of the well casing.

The down well flow control valve in FIG. **17** can be used for operation in the regeneration mode when supplying water to the upper aquifer **904** (as shown in FIG. **17**), for example, when the pump is located above the down well flow control valve. The down well flow control valve of FIG. **17** can also be installed above a pump and submersible electric motor combination (e.g., as shown in FIGS. **12**, **13**, and **20-22**), enabling regeneration mode operation during water injection into the lower aquifer **906**. In certain embodiments, a pump (e.g., a line shaft pump) can be disposed above the down well flow control valve **902** and a submersible pump/motor assembly can be disposed below the down well flow control valve **902** to enable operation in the regeneration mode when recharging both the upper aquifer **904** and the lower aquifer **906**.

FIGS. **18-19** illustrate another exemplary well column **1000** including a pipe section **1002**. For example, the pipe section **1002** can be a six-inch inside diameter steel pipe having threads **1004**, **1006** at its opposite ends for coupling to associated pipe components. The pipe **1002** can include at least one aquifer recharge outlet (e.g., comprising a plurality of apertures) through which liquid can pass to recharge an aquifer. FIG. **18** illustrates an exemplary plurality of apertures **1008** disposed in a spiral pattern along a section **1010** of the pipe **1002**. FIG. **19** illustrates a vertical sectional view through a portion of pipe section **1002**. The pipe section **1002** comprises a valve **1012** movable between a first position wherein the valve **1012** does not overlie and seal the apertures **1008** and a second position in which the valve **1012** overlies and closes the apertures. When open, as shown in FIG. **19**, a flow path (shown by arrows **1014**) exists through the center of the pipe section **1002** and outwardly through the apertures **1008**. The valve **1012** can be positioned within a support structure, such a cage structure **1016**. The cage structure can comprise upper and lower cross-pieces **1018**, **1020** with the valve **1012** retained between them, and a plurality of braces **1022** extending between the upper and lower cross-pieces. A drive mechanism can be provided for shifting the cage **1016** and therefore the valve **1012** between the open and closed position. It should be noted that a plurality of open positions are provided depending on the number of apertures **1008** that are exposed. The drive mechanism can include at least one, and in the illustrated embodiment, two, valve closing cylinders **1024** and at least two valve operating cylinders **1026**. Extension and/or retraction of the cylinders **1024**, **1026** can open and close the valve **1012**. Further details of exemplary down well flow control valves can be found, for example, in U.S. Pat. Nos. 8,522,887 and 7,156,578, which are incorporated herein by reference. In certain embodiments, the down well flow control valve can also comprise springs or other biasing mechanisms to bias the valve, shroud, etc., to the closed position. Further details regarding such valve configurations can be found in U.S. Publication No. 2006/0127184, which is incorporated herein by reference.

Example 9: Down Well Flow Control Valve Assembly with Sleeve

FIGS. **20** and **21** illustrate an embodiment of an assembly **1100** comprising a down well flow control valve **1102** received at least partially within and coupled to a sleeve or conduit **1104**. The assembly is shown disposed in a well bore **1114**. The down well flow control valve **1102** can be coupled to the well column pipe above it by a threaded portion **1152** at the upper end of the valve. The down well flow control valve **1002** can comprise a plurality of openings or apertures **1106** through which water can flow, and can be configured according to any of the flow control valve embodiments described herein.

The sleeve **1104** can comprise a first, upper, or inlet portion **1108**, a second, tapered intermediate portion **1110**, and a third, lower, or outlet portion **1112**. The first portion **1108** can have a first diameter D1 that is greater than a second diameter D2 of the outlet portion **1112**. The diameter of the intermediate portion **1110** can taper between the first diameter D1 and the second diameter D2. The outlet portion **1112** can be coupled to a conduit or well column pipe **1116** at a coupling **1124**, and the conduit **1116** can extend deeper into the well bore **1114**. The conduit **1116** can have the second diameter D2. In certain embodiments, the conduit **1116** can be coupled to a pump **1118**, and optionally to a combination pump and submersible electric motor **1120** as illustrated in FIG. **20**. In the illustrated embodiment, a screen or mesh **1122** can be disposed between the pump **1118** and the electric motor **1120**. The conduit **1116** can have any length. In certain embodiments, the pump **1118** can be coupled directly to the outlet portion **1112** of the sleeve **1104**. The sleeve **1104** can thus be in fluid communication with the pump **1118**.

In the illustrated embodiment, the sleeve **1104** can be coupled to the exterior body/casing/shell **1126** of the down well flow control valve **1102** by a coupling **1128**. FIG. **21** illustrates the coupling **1128** in greater detail. In the illustrated embodiment, the coupling **1128** can be an assembly comprising a flange member **1130** coupled to the down well flow control valve **1102** and a flange member **1134** coupled to the interior surface of the sleeve **1104**. The flange member **1130** can be welded to the casing **1126** of the down well flow control valve **1102**, as shown at **1132**, or can be integrally formed with the casing. As used herein, the terms "integrally formed" and "unitary construction" refer to a construction that does not include any welds, fasteners, or other securing means for securing two features together. The flange member **1134** can be positioned within the bore of the inlet portion **1108** of the sleeve **1104**. In the illustrated embodiment, the flange member **1134** is welded to the inside wall of the inlet portion **1108** at a weld **1136**, although it will be understood that the flange member **1134** can also be integrally formed with the sleeve **1104** such that the sleeve and flange are a unitary construction.

Each of the flanges **1130** and **1134** can define a plurality of openings configured to be aligned with one another when the sleeve **1104** is coupled to the down well flow control valve **1102**, and through which fastener members can be inserted to secure the flange members together. For example, with reference to FIG. **21**, the flange member **1130** can define an opening **1138** and the flange member **1134** can define a corresponding opening **1140** through which a fastener member configured as a bolt **1142** is inserted. In the illustrated embodiment, the opening **1140** can be threaded, although in other embodiments both openings can be threaded, and/or the bolt can be secured in place with a nut.

In certain embodiments, the coupling **1128** can further comprise one or more sealing members. For example, in certain embodiments one or both of the flange members **1130**, **1134** can be configured to accommodate a sealing member. In the illustrated embodiment, the flange member **1130** defines a groove or channel **1144** extending circumferentially around the radially outward surface of the flange, and in which a sealing member configured as an O-ring **1146** is received. In certain embodiments, a sealing member such as an O-ring and/or a gasket can also be disposed between the flange members **1130** and **1134** such that tightening the bolts **1142** compresses the sealing member and seals the space between the flange members. In certain embodiments, the flange member **1134** can be positioned above the flange member **1130**. In such a configuration, the flange member **1130** can have a smaller diameter to allow the weld **1136** to extend beyond the flange **1130**.

In the illustrated embodiment, a one-way valve such as a check valve **1148** can be coupled to the lower or distal end of the down well flow control valve casing **1126**. The check valve **1148** can be configured to permit flow upwardly in FIG. **20** into the down well flow control valve **1102**, and to restrict flow downwardly through the check valve into the well column.

During operation in the pumping mode, the pump **1118** can pump water upwardly in FIG. **20**, causing the check valve **1148** to open. The apertures **1106** of the down well flow control valve **1102** can be closed such that water can flow through the down well flow control valve **1102** and upwardly through the well column pipe to, for example, the source reservoir. The sealed coupling **1128** can prevent water flow out of the top of the sleeve **1104**. During operation in the regeneration mode, the apertures **1106** of the down well flow control valve **1102** can be opened, and water can flow through the down well flow control valve and into the inlet portion **1108** of the sleeve **1104**, as indicated at **1150** in FIG. **21**. The water can then flow through the outlet portion **1112** of the sleeve **1104** (thereby bypassing the check valve **1148**), through the conduit **1116**, and into the pump **1118**, where it can spin the pump and the electric motor in the reverse direction to generate electricity as described above. The assembly **1100** thereby allows bi-directional water flow through the down well flow control valve **1102** without requiring any significant modifications to the down well flow control valve. Accordingly, existing well systems with down well flow control valves as described herein can be modified with the sleeve **1104** and other components of the assembly **1100** to permit operation in the pumping mode and the regeneration mode as described herein.

In yet another embodiment, the position of the coupling **1128** can be varied according to the particular requirements of the system to allow a portion of water flow through the down well flow control valve **1102** to flow through the sleeve **1104** to the pump **1118**, while at the same time allowing a portion of the water to flow out of the down well flow control valve, bypass the sleeve **1104**, and flow directly into the aquifer without passing through the pump. Such a configuration is shown in FIG. **22**, in which the down well flow control valve **1102** comprises two groups of apertures **1106**, one group of apertures **1106**A being above the coupling **1128** and one group of apertures **1106**B being disposed within the sleeve **1104**. Accordingly, when water flows into the aquifer, a portion of the water flow will be directed through the apertures **1106**B into the sleeve and thence to the pump **1118** to generate electricity, and a portion of the water flow will flow out of the openings **1106**A and directly into the aquifer, bypassing the pump. Such a configuration can be advantageous in scenarios where it is desirable to recharge or refill the aquifer faster than can be achieved by directing 100% of the water through the pump **1108** in the regeneration mode. In certain embodiments, the proportion of apertures **1106**A and/or **1106**B that are uncovered to permit flow can be controlled/varied between 0% to 100%. In certain embodiments, a valve cover or member similar to the valve member **916** in FIG. **17** can move upwardly in FIG. **22** to uncover the groups of apertures **506**B and **506**A, with the apertures **506**B inside the sleeve **1104** being uncovered first when the valve is opened.

Explanation of Terms

For purposes of this description, certain aspects, advantages, and novel features of the embodiments of this disclosure are described herein. The disclosed methods, apparatus, and systems should not be construed as being limiting in any way. Instead, the present disclosure is directed toward all novel and nonobvious features and aspects of the various disclosed embodiments, alone and in various combinations and sub-combinations with one another. The methods, apparatus, and systems are not limited to any specific aspect or feature or combination thereof, nor do the disclosed embodiments require that any one or more specific advantages be present, or problems be solved.

Although the operations of some of the disclosed embodiments are described in a particular, sequential order for convenient presentation, it should be understood that this manner of description encompasses rearrangement, unless a particular ordering is required by specific language set forth below. For example, operations described sequentially may in some cases be rearranged or performed concurrently. Moreover, for the sake of simplicity, the attached figures may not show the various ways in which the disclosed methods can be used in conjunction with other methods. Additionally, the description sometimes uses terms like "provide" or "achieve" to describe the disclosed methods. These terms are high-level abstractions of the actual operations that are performed. The actual operations that correspond to these terms may vary depending on the particular implementation and are readily discernible by one of ordinary skill in the art.

All features described herein are independent of one another and, except where structurally impossible, can be used in combination with any other feature described herein.

As used in this application and in the claims, the singular forms "a," "an," and "the" include the plural forms unless the context clearly dictates otherwise. Additionally, the term "includes" means "comprises." Further, the terms "coupled" and "associated" generally mean electrically, electromagnetically, and/or physically (e.g., mechanically or chemically) coupled or linked and does not exclude the presence of intermediate elements between the coupled or associated items absent specific contrary language.

In the present description, certain terms may be used such as "up," "down," "upper," "lower," "horizontal," "vertical," "left," "right," and the like. These terms are used, where applicable, to provide some clarity of description when dealing with relative relationships. But, these terms are not intended to imply absolute relationships, positions, and/or orientations. For example, with respect to an object, an "upper" surface can become a "lower" surface simply by turning the object over. Nevertheless, it is still the same object.

Unless otherwise indicated, all numbers expressing quantities of components, forces, moments, molecular weights, percentages, temperatures, times, and so forth, as used in the specification or claims are to be understood as being modified by the term "about." Accordingly, unless otherwise indicated, implicitly or explicitly, the numerical parameters set forth are approximations that can depend on the desired properties sought and/or limits of detection under test conditions/methods familiar to those of ordinary skill in the art. When directly and explicitly distinguishing embodiments from discussed prior art, the embodiment numbers are not approximates unless the word "about" is recited. Furthermore, not all alternatives recited herein are equivalents.

Although there are alternatives for various components, parameters, operating conditions, etc., set forth herein, that does not mean that those alternatives are necessarily equivalent and/or perform equally well. Nor does it mean that the alternatives are listed in a preferred order unless stated otherwise.

In view of the many possible embodiments to which the principles of the disclosed technology may be applied, it should be recognized that the illustrated embodiments are only examples and should not be taken as limiting the scope of the disclosure. Rather, the scope of the disclosure is at least as broad as the following claims and equivalents of the features recited therein. We therefore claim all that comes within the scope and spirit of these claims.

The invention claimed is:

1. An aquifer storage and recovery system, comprising:

a pump in communication with a well bore that communicates with a subterranean aquifer formation;

an electric motor coupled to the pump;

a drive unit configured to control operation of the electric motor; and

a controller configured to:

flow water into the well bore from a source reservoir through the pump and into the subterranean aquifer formation such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate as a generator;

determine a power output of the electric motor;

determine a difference between the power output of the electric motor and a first power output set point;

operate the drive unit to control a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the first power output set point by varying a frequency of a drive signal output by the drive unit to the electric motor; and

wherein the controller is further configured to detect an increase in power output beyond the first power output set point after changing the frequency of the drive signal and store the increased power output as a new power output set point.

2. The aquifer storage and recovery system of claim **1**, further comprising a regeneration module connected to the drive unit and comprising inverter circuitry configured to convert direct current supplied to the drive unit from the electric motor to alternating current.

3. The aquifer storage and recovery system of claim **2**, wherein a direct current (DC) bus of the regeneration module is connected to a DC bus of the drive unit.

4. The aquifer storage and recovery system of claim **1**, further comprising a down well flow control valve in the well bore, and wherein the controller is configured to operate the down well flow control valve to maintain pressure in the well bore at a pressure set point.

5. The aquifer storage and recovery system of claim **4**, wherein:

the down well flow control valve is coupled to a sleeve and coupled to a one-way valve, the one-way valve being disposed within the sleeve;

the pump is disposed below the down well flow control valve and is in fluid communication with the sleeve; and

the sleeve and the one-way valve are configured such that water flow into the subterranean aquifer formation flows through the sleeve to the pump and bypasses the one-way valve, and water flow out of the subterranean aquifer formation flows into the sleeve, through the one-way valve, and into the down well flow control valve.

6. The aquifer storage and recovery system of claim **1**, wherein the controller is further configured to:

determine a first theoretical power output of the electric motor based at least in part on a flow rate through the well bore, a water level in the source reservoir, a pressure in the well bore, a numerical constant associated with the aquifer storage and recovery system, or any combination thereof;

determine a difference between the first theoretical power output and a previously stored theoretical power output; and

control the rotational speed of the electric motor based at least in part on the difference between the first theoretical power output and the previously stored theoretical power output.

7. The aquifer storage and recovery system of claim **1**, wherein the controller is further configured to vary the frequency of the drive signal again after the increased power output is stored as the new power output set point.

8. The aquifer storage and recovery system of claim 1, wherein the controller is further configured to determine a first rotational speed of the electric motor and the pump, and operate the drive unit to control the electric motor such that it rotates at a second rotational speed that is less than the first rotational speed.

9. A pumped-storage hydroelectric system including the aquifer storage and recovery system of claim 1.

10. A method, comprising pumping water from the subterranean aquifer formation into the source reservoir with the aquifer storage and recovery system of claim 1, wherein the electric motor is powered with electricity supplied by a renewable energy power plant.

11. A method, comprising:

with an aquifer storage and recovery system comprising a well bore, a pump in fluid communication with the well bore, an electric motor coupled to the pump, and a drive unit configured to control operation of the electric motor, flowing water into a subterranean aquifer formation through the well bore such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate the electric motor as a generator;

determining a power output of the electric motor;

determining a difference between the power output of the electric motor and a first power output set point; and

with the drive unit, controlling a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the first power output set point by varying a frequency of a drive signal output by the drive unit to the electric motor;

detecting an increase in power output beyond the first power output set point after changing the frequency of the drive signal; and

storing the increased power output as a new power output set point.

12. The method of claim 11, further comprising varying the frequency of the drive signal again after the increased power output is stored as the new power output set point.

13. The method of claim 11, wherein flowing water into the well bore further comprises maintaining a pressure in the well bore at or above a pressure set point.

14. The method of claim 11, further comprising:

prior to determining the power output of the electric motor, determining a rotational speed of the electric motor; and

with the drive unit, outputting a drive signal having a frequency matched to the rotational speed of the electric motor.

15. The method of claim 14, further comprising reducing the frequency of the drive signal.

16. The method of claim 11, further comprising:

determining a change in a theoretical power output of the aquifer storage and recovery system; and

varying a frequency of a drive signal output to the electric motor by the drive unit.

17. The method of claim 11, further comprising varying a position of a flow control valve disposed in the well bore to maintain a pressure in the well bore at a pressure set point.

18. An aquifer storage and recovery system, comprising:

a pump disposed in a well bore that communicates with a subterranean aquifer formation;

an electric motor coupled to the pump;

a drive unit configured to control operation of the electric motor;

a down well flow control valve disposed in the well bore and in fluid communication with the pump; and

a controller configured to:

flow water into the well bore from a source reservoir through the pump and into the subterranean aquifer formation such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate as a generator;

operate the down well flow control valve to maintain pressure in the well bore at a pressure set point;

determine a power output of the electric motor;

determine a difference between the power output of the electric motor and a first power output set point; and

operate the drive unit to control a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the first power output set point by varying a frequency of a drive signal output by the drive unit to the electric motor;

wherein the controller is further configured to detect an increase in power output beyond the first power output set point after changing the frequency of the drive signal and store the increased power output as a new power output set point.

19. An aquifer storage and recovery system, comprising:

a pump disposed in a well bore;

an electric motor coupled to the pump;

a drive unit configured to control operation of the electric motor;

a down well flow control valve disposed in the well bore, the down well flow control valve being coupled to a sleeve and coupled to a one-way valve, the one-way valve being disposed within the sleeve, the pump being disposed below the down well flow control valve and in fluid communication with the sleeve, wherein the sleeve and the one-way valve are configured such that water flow into an aquifer flows through the sleeve to the pump and bypasses the one-way valve, and water flow out of the aquifer flows into the sleeve, through the one-way valve, and into the down well flow control valve; and

a controller configured to:

flow water into the well bore from a source reservoir through the pump such that the pump rotates in a reverse direction and drives the electric motor coupled to the pump in the reverse direction to operate as a generator;

determine a power output of the electric motor;

determine a difference between the power output of the electric motor and a power output set point;

operate the drive unit to control a rotational speed of the electric motor based at least in part on the difference between the power output of the electric motor and the power output set point; and

operate the down well flow control valve to maintain pressure in the well bore at a pressure set point.

20. The aquifer storage and recovery system of claim 19, wherein operating the drive unit to control the rotational speed of the electric motor further comprises changing a frequency of a drive signal output by the drive unit to the electric motor.

21. The aquifer storage and recovery system of claim 20, wherein the controller is further configured to:

detect an increase in power output after changing the frequency of the drive signal; and store the increased power output as a new power output set point.

22. The aquifer storage and recovery system of claim 19, wherein the controller is further configured to vary the frequency of the drive signal again after the increased power output is stored as the new power output set point.

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